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JOURNAL OF THE IRON AND STEEL INSTITUTE

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by J. A. Bond and T. Sanderson

The Present Position of the Converter Process
by B. Matuschka

Cold Rolling with Strip Tension : Pt. I
by H. Ford, F. Ellis, and D. R. Bland

Residual Stresses in Cylindrical Bars...*by H. Föppl*

Works Trial of a Metering Pump
by A. L. Cude and J. Stringer

Determination of Tin in Ferro-Tungsten and Tungsten Metal

Report of Council for 1950

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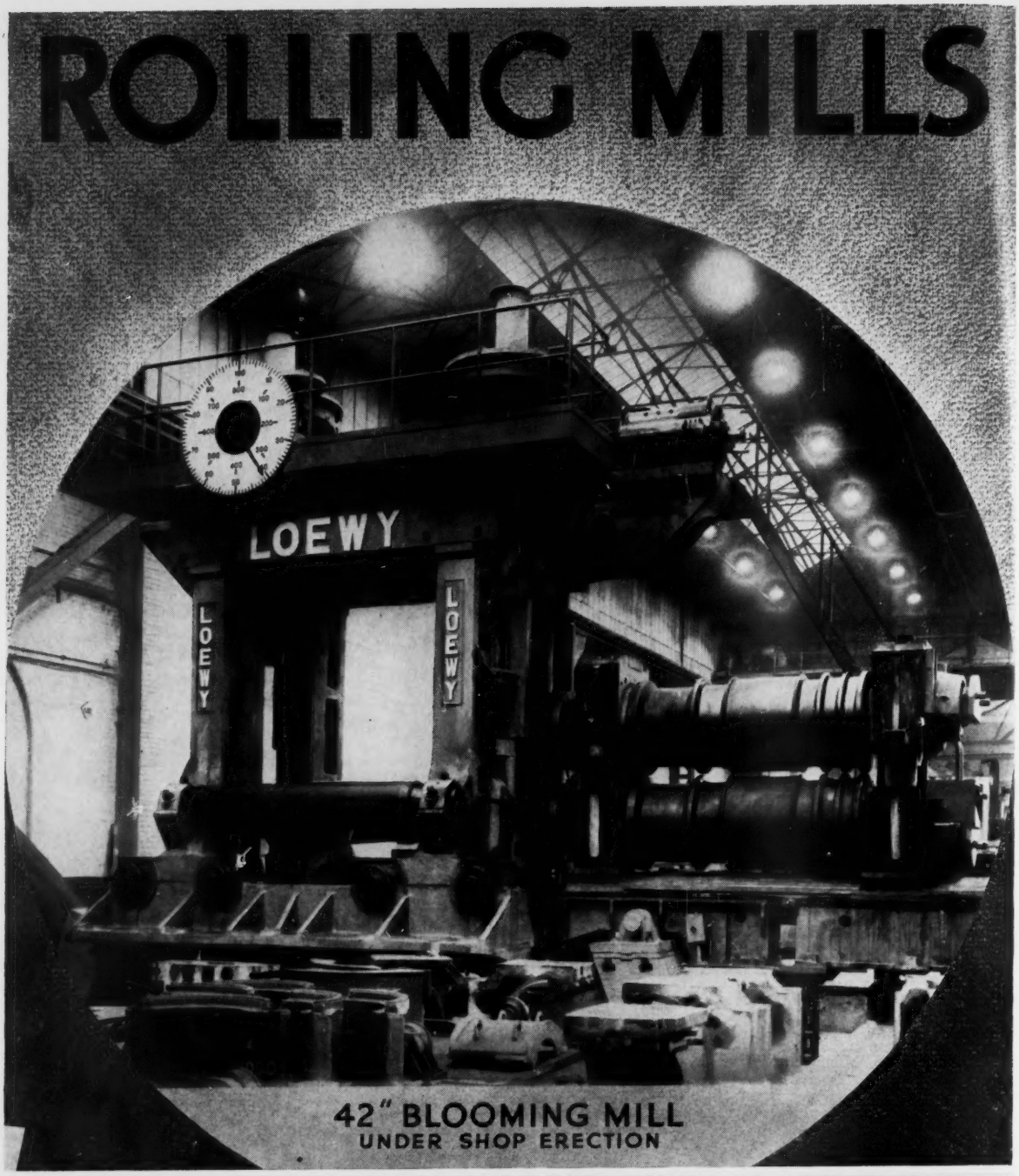
ROLLING MILLS



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Volume 168

1951

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ABBREVIATIONS AND SYMBOLS

Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled ; alternating current
A.H.	air-hardened
amp.	ampère(s)
amp.hr.	ampère-hour(s)
approx.	approximately
at.-%	atomic per cent
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade ; Celsius (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dia.	diameter
dil.	dilute
dm.	decimetre(s)
e.m.f.	electromotive force
e.v.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kg.	kilogramme(s)
kg.cal.	kilogramme-calorie(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units

l.	litre(s)
lb.	pound(s)
L.F.	low-frequency
M	molar (solution)
m.	metre(s)
m.amp.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum ; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth ; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc ; foot (feet)
″	second of arc ; inch(es)
$<$	less than
$>$	greater than
$\nless$	not less than
$\ngtr$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\simeq$	approximately equal to
$\propto$	proportional to

Unless otherwise stated above, the symbols given in the following British Standards are used in the *Journal*: Chemical, Thermodynamical, and Physico-chemical quantities: B.S. 813; Engineering units: B.S. 560.

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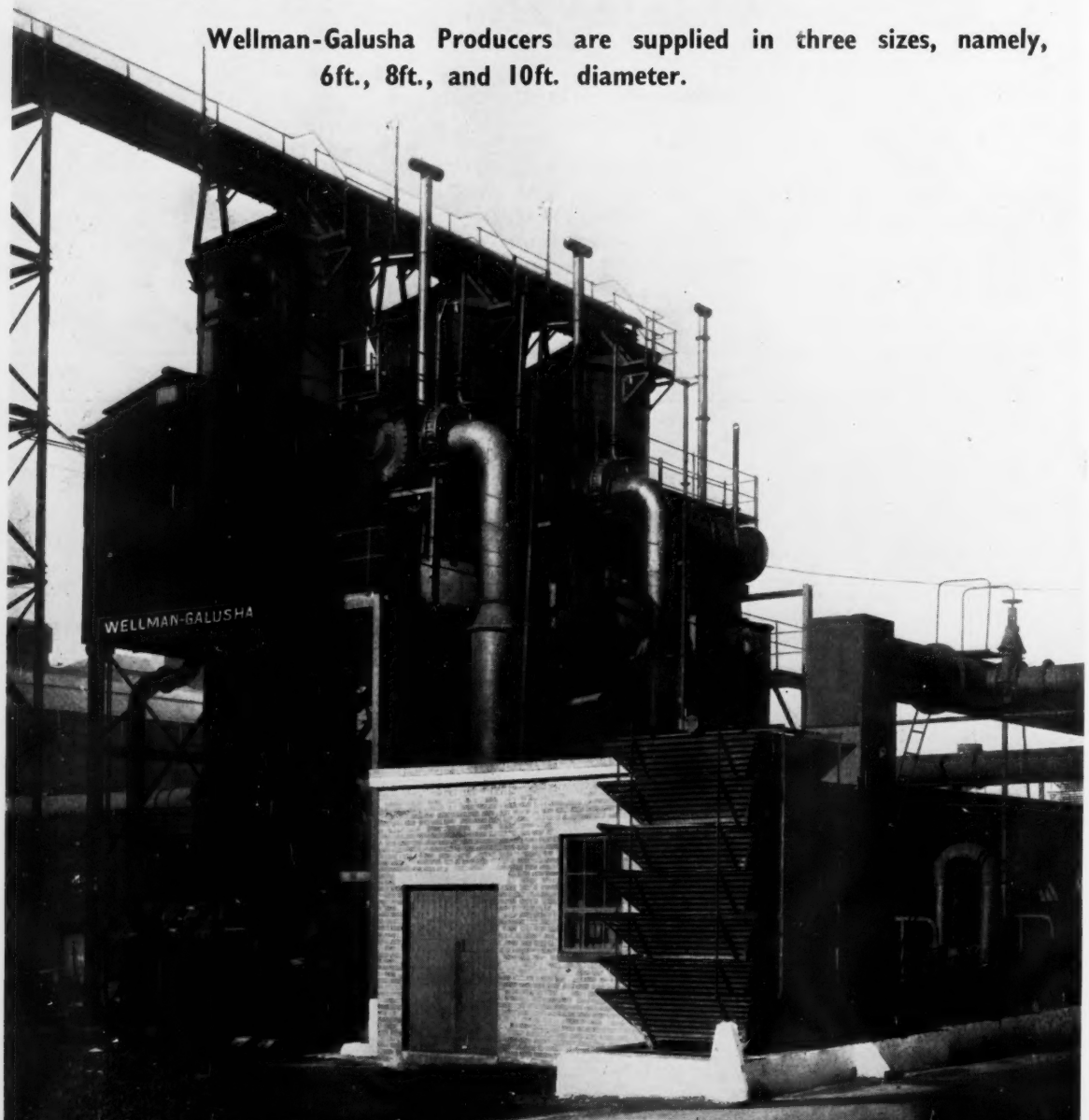

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BENJAMIN F. FAIRLESS

BENJAMIN F. FAIRLESS, President of the United States Steel Corporation was born in Pigeon Run, Ohio, in 1890, the son of Mr. and Mrs. David D. Williams. Later he was legally adopted by his uncle and aunt, Mr. and Mrs. Jacob Fairless of Justus, Ohio.

After completing school at Justus, Mr. Fairless enrolled at Wooster College, transferring later to Ohio Northern University, where he graduated with a degree in Civil Engineering in 1913. In 1935, he was awarded an honorary degree of Doctor of Engineering; in 1937 he received from Kent State University, Ohio, an honorary D.Sc. degree, and a third honorary degree of D.Sc. was bestowed upon him by Pittsburgh University, in 1943. Four additional honorary degrees have since been conferred upon Mr. Fairless by various colleges.

His business career began in 1913, when he became a civil engineer for the Wheeling and Lake Erie Railroad, and two months later in the same capacity, with the Central Steel Company of Massillon, Ohio. He was rapidly promoted, and became Vice-President in charge of operations. When the company was amalgamated with the United Alloy Steel Corporation, in 1926, Mr. Fairless was appointed Vice-President and General Manager of the successor company– Central Alloy Steel, a position he held until he became President and General Manager in 1928. In 1930, when the company was one of several united in the formation of the Republic Steel Corporation, Mr. Fairless entered the new organization as Executive Vice-President.

Five years later, in 1935, he accepted the Presidency of the Carnegie-Illinois Steel Corporation, formed by uniting several subsidiaries of the United States Steel Corporation. On 1st January, 1938, he succeeded W. A. Irvin as President of the United States Steel Corporation, having been elected a Director a few months earlier. In the Spring of the same year he was appointed Chief Administrative Officer of the Corporation.

During the Second World War, in 1942, Mr. Fairless was appointed a member of the Advisory Staff of the Chief of Ordnance, War Department. He was also a member of the Iron and Steel Industry Advisory Committee of the War Production Board. For his services in these capacities he was awarded the Medal for Merit in 1946.

The Bessemer Medal was awarded to Mr. Fairless in 1951 in recognition of his distinguished services to the iron and steel industry. He is a Vice-President and a Director of the American Iron and Steel Institute.

XUM

Benjamin F. Fairless
Bessemer Medallist 1951

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

REPORT OF COUNCIL FOR 1950

THE Council submit this, their Annual Report and Statement of Accounts for the year 1950, to Members for their approval at the Eighty-second Annual General Meeting of The Iron and Steel Institute.

The work of the Institute was continued successfully throughout the period covered by the Report.

The year was the centenary of the birth of Sidney Gilchrist Thomas, an event which was commemorated by a lecture held at the Annual Meeting of the Institute and by meetings organized by Societies in several other countries.

During September a successful Special Meeting was held in Glasgow. This was the first large meeting to be organized by the Institute in Great Britain outside London since the Autumn Meeting held at Middlesbrough in 1937.

Income exceeded expenditure by a substantial sum, the credit balance being nearly four times as large as that at the end of the previous year.

ROLL OF THE INSTITUTE

For the first time since 1941 there was a reduction in the number of Members of the Institute. The total at 31st December, 1950, was 4882, compared with 4909 at 31st December, 1949.

This reduction is due entirely to the smaller numbers of Associate Members (702 instead of 857 a year ago) and especially of Associate Members who are resident in the United Kingdom, and are Members also of the Institute of Metals or of the Institution of Metallurgists (a reduction from 516 to 399). The number of Associate Members living overseas hardly changed (80 instead of 83).

The number of Ordinary and Life Members increased from 4025 to 4149, and at the end of the year was greater than on any previous occasion; the increase is evenly divided between the Home and Overseas Membership (61 Home, 63 Overseas).

During the year, 333 Ordinary and Associate Members were newly elected or reinstated. The deaths of 45 were reported; 225 resigned, 73 were struck off the Roll of Members, and 17 elections lapsed for non-payment of the subscriptions due.

An analysis of the membership at 31st December, 1950, is given in Table I, whilst the membership trend since the Institute was founded is shown in Fig. 1.

OBITUARY

The Council regret to announce the deaths of 45 Members; of these the following 37 occurred during 1950:

ALEXANDER, M. (Warrington) ...	15th March
BEDSON, N. P. (Southport, Lancs.)	22nd May
BOSTEM, H. (Ougrée, Belgium) ...	27th July
CALVERT, F. (Leeds)	25th March
CHRISTMAS, E. B. (London) ...	31st May
CRICHTON, *Sir* Robert (Warrington)	8th May
DARLING, H. G. (Melbourne, Australia)	26th January
DICKIE, *Dr.* H. A. (Corby, Northants)	2nd May
FARMER, J. H. (West Hartlepool)...	8th November
FRIEDMAN, P. (London)	25th November
GEORGE, *Sir* Edward J. (Consett, Co. Durham)	25th October
GILLETT, *Dr.* H. W. (Columbus, Ohio, U.S.A.)	3rd March
GREENLY, *Lt.-Col. Sir* John (London)	31st December
GRIFFITHS, Roosevelt (Swansea) ...	24th June
HOPKINS, H. (Port Talbot, Glam.)	12th March
HOUBAER, E. (Tilleur, Belgium) ...	19th February
HUTTON, W. G. (Cambuslang, Lanarks.)	25th February
JACKSON, S. A. (Sheffield) ...	30th April
LOVING, H. C. (Cranbrook, Kent)...	7th February
MONTEIRO, J. de M. (Rio de Janiero, Brazil)	Date Unknown
MUSCROFT, E. B. (London) ...	20th February
NEWELL, A. P. (Glasgow)	18th February
NEWTON, S. G. (Retford, Notts.) ...	22nd December
OSBORN, F. M. (Sheffield)	8th November
REES, *Dr.* W. J. (Sheffield) ...	April
RIPPON, J. E. (Manchester) ...	14th April
ROBERTS, D. E. (Cardiff)	21st July
ROTCHELL, J. (Sheffield)	Date Unknown
SCOTT, H. K. (Chesham Bois, Bucks.)	Date Unknown
SMITH, Harry (Redcar, Yorks.) ...	6th March
SPEAKMAN, J. E. D. (Sheffield) ...	28th August
VILLAGE, R. (Dronfield, Yorks.) ...	25th March
WHILE, A. J. (Tettenhall, Staffs.)...	Date Unknown
WILLIAMS, E. A. (Swansea) ...	16th November
WILLIS, S. (Sheffield)	7th August
WRIGHT, A. (Scarborough) ...	11th January
WRIGHT, *Col. Sir* W. Charles, Bt. (Ascot, Berks.)	18th August

The deaths of the following eight Members took place in 1949, but were only subsequently made known to the Institute:

Table I—MEMBERSHIP OF THE IRON AND STEEL INSTITUTE AT 31ST DECEMBER, 1950, AND COMPARISON WITH 1949

	Membership at 31st December, 1950												1949		
	Ordinary Membership		Joint Membership with—								Total Membership		Total Membership		Grand Totals
			Institute of Metals		Institution of Metallurgists		Both Institute and Institution		Totals						
	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	
Patron	1	...	...	...	...	...	...	...	...	...	1	...	1	...	1
Members:															
Hon. Vice-Presidents	10	5	2	...	...	...	...	...	2	...	12	5	11	4	15
Hon. Members	2	3	2	...	...	...	...	...	2	...	4	3	3	4	7
Non-Paying Members	5	1	...	...	...	...	...	...	...	...	5	1	3	1	4
Life Members	61	21	2	5	6	...	4	...	12	5	73	26	24	74	98
Ordinary Members	1748	742	408	306	393	34	380	39	1181	379	2929	1121	2867	1060	3927
Total (Members)	1827	772	414	311	399	34	384	39	1197	384	3024	1156	2959	1093	4052
Associate Members	223	39	287	34	44	5	68	2	399	41	622	80	774	83	8579
Total (both classes)	2050	811	701	345	443	39	452	41	1596	425	3646	1236	3733	1176	4909

CARLSSON, C. H. (Storangen, Sweden) ... ... 22nd December
HARRISON, G. H. (Swansea) ... 1st April
HUDSON, A. J. (Vereeniging, South Africa) ... ... 5th August
MEYER, F. W. (Winterthur, Switzerland) ... ... 21st November
NIEDRINGHAUS, H. (Granite City, Ill., U.S.A.) ... ... July
NILLSON, A. H. (Eskelstuna, Sweden) ... ... 28th October
SUMMERS, J. W. (Thornaby-on-Tees, Yorks.) ... ... 14th November
SUNSTROM, H. R. (Gunnebo Bruk, Sweden) ... ... 21st November

Although Mr. J. C. Kjellberg (Stockholm, Sweden) died in 1942 the Institute was not informed until recently; the Council record his death with much regret. Mr. Kjellberg was an Honorary Member of the Institute, and had been elected in 1895.

Sir Charles Wright was a Past-President and Honorary Member of the Institute; Sir Edward George and Sir John Greenly were Honorary Vice-Presidents.

During the year the Institute lost several of its oldest Members: Mr. Roberts (1891—a Life Member), Mr. Scott (1896—a Life Member) and Mr. While (1897—a Life Member) had been members for over fifty years, and Mr. Carlsson (1904), Mr. Christmas (1908), Sir Robert Crichton (1907), and Sir Charles Wright (1902—a Life Member) for over forty years.

CHANGES ON THE COUNCIL

President-Elect

At the Autumn General Meeting it was announced that the Council had unanimously decided to nominate Mr. Richard Mather to become President at the Annual General Meeting in 1951.

Other Changes

During 1950 Professor J. H. Andrew (Member of Council) was nominated to be a Vice-President, and Mr. E. F. Law (Member of Council) to be an Honorary Vice-President. Sir Charles Bruce-Gardner, Bt. (Messrs. John Lysaght, Ltd.), and Mr. G. H. Johnson (Kettering Iron and Coal Co., Ltd.) accepted invitations to become Members of Council.

The following agreed to serve as Honorary Members of Council during their presidencies of the Societies named, in succession to their predecessors: Mr. H. S. Tasker (Institute of Metals, following Sir Arthur Smout), Mr. G. B. Thomas (Cleveland Institution of Engineers, following Mr. E. T. Judge), Mr. J. H. Steele, (Ebbw Vale Metallurgical Society, following Mr. R. C. Powell), Mr. G. W. Green (Leeds Metallurgical Society, following Mr. J. Wilkinson), Mr. A. Jackson (Lincolnshire Iron and Steel Institute, following Mr. H. M. Henderson), Mr. H. Edwards (Liverpool Metallurgical Society, following Dr. S. J. Kennett), Mr. E. J. Heeley (Manchester Metallurgical Society, following Dr. D. Binnie), Mr. G. H. Latham (Newport and District Metallurgical Society, continuing presidency), Dr. James White (Sheffield Metallurgical Association, following Mr. A. Roebuck), Professor H. W. Swift (Sheffield Society of Engineers and Metallurgists, following Mr. B. W. Doncaster), Mr. H. K. Knight (Staffordshire Iron and Steel Institute, following Dr. E. Marks), Captain H. J. Thomas (Swansea and District Metallurgical Society, following the late Mr. Roosevelt Griffiths), and Mr. W. Barr (West of Scotland Iron and Steel Institute, continuing presidency). Mr. W. E. Bardgett and Mr. W. W. Stevenson continued to represent the Institution of Metallurgists.

It was decided that the Chairman of the Institute's Engineering Committee should be an Honorary Member of Council during his tenure of that office: accordingly Mr. C. H. T. Williams was so nominated to be an Honorary Member of Council when he succeeded Mr. W. F. Cartwright as Chairman of the Engineering Committee.

In accordance with Bye-Law No. 10, the following names of Vice-Presidents and Members of Council due to retire at the Annual General Meeting, 1951, were announced at the Autumn Meeting, 1950 :

Vice-Presidents—Mr. G. Steel, The Hon. R. G. Lyttelton and Captain H. Leighton Davies, C.B.E.

Members of Council—Mr. C. R. Wheeler, C.B.E., Mr. D. A. Oliver, Dr. C. Sykes, F.R.S., Mr. W. Barr and Sir Arthur Matthews, O.B.E.

No other Members having been nominated up to one month before the Annual General Meeting, the retiring Members are presented for re-election.

AWARDS

The Bessemer Gold Medal for 1950 was awarded to Mr. James Mitchell, C.B.E. (Honorary Treasurer), for his distinguished contributions to the technical development of the iron and steel industry in Great Britain.

The Sir Robert Hadfield Medal for 1950 was awarded to Mr. G. D. Elliot (Appleby-Frodingham Steel Co.) for his contributions in practice and theory to the development of blast-furnace operation.

An Andrew Carnegie Silver Medal for 1949 was presented to Mr. N. H. Polakowski (University College, Swansea) for his Andrew Carnegie Research Report on "*The Compression Test in Relation to Cold Rolling*" (*Journal*, 1949, vol. 163, Nov., pp. 250–276).

The Williams Prize for 1949 was presented jointly to Dr. D. F. Marshall and Mr. H. C. White (both of Park Gate Iron and Steel Co., Ltd.) for their paper on "*The Conversion to Oil Firing of the Open-Hearth Furnaces at Park Gate Works*" (*Journal*, 1949, vol. 161, Apr., pp. 301–317).

The Ablett Prize for 1949 was awarded jointly to Mr. E. L. Diamond (British Standards Institution, formerly of British Iron and Steel Research Association) and Mr. A. M. Frankau (British Iron and Steel Research Association) for their paper on "*Present Methods of Open-Hearth Furnace Charging*" (*Journal*, 1949, vol. 161, Mar., pp. 191–211).

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS

The following awards were made from the Andrew Carnegie Research Fund during 1950:

J. Burke (Liverpool University): £50 to assist a research on the decomposition of the carbide constituent in high-purity cast irons.

J. P. Hugo (Sheffield University): £150 for an investigation into the tensile properties of aggregates of ferrite and pearlite.

A. Rodgers (Sheffield University): £250 for a research on the internal friction of steels with special reference to grain-boundary phenomena.

MOND NICKEL FELLOWSHIPS

The terms of office of all Members of The Mond Nickel Fellowships Committee, with the exception of Lt.-Col. Sir John Greenly, K.C.M.G., representing the Institute of Metals, finished in May, 1950.

Dr. C. H. Desch, F.R.S. (representing The Iron and

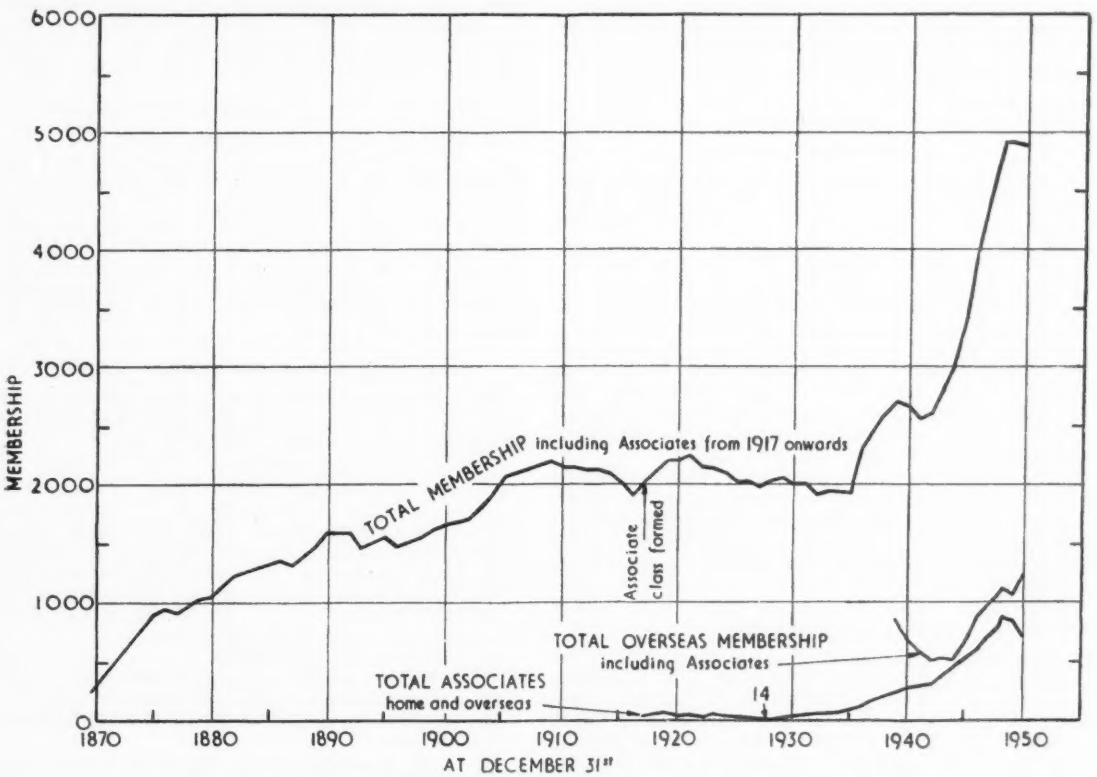

Fig. 1—Variations in Membership since the foundation of the Institute in 1869

Steel Institute) resigned, and Mr. F. H. Saniter (The United Steel Companies, Ltd.) agreed to serve in his place.

Mr. J. W. Gardom, Mr. E. D. McDermott, Dr. J. W. Jenkin and Dr. L. B. Pfeil (representing, respectively, the Institute of British Foundrymen, The Institution of Mining and Metallurgy, The Institution of Metallurgists and The Mond Nickel Co., Ltd.) agreed to serve for a further period of three years.

Dr. J. W. Jenkin agreed to be Chairman of the Committee in place of Dr. C. H. Desch.

The Committee made the following awards for 1950:

D. ALEXANDER (University of Otago, Dunedin, New Zealand), to study industrial technique and the application of research to metallurgical control in Great Britain, with special reference to tinning, plating, enamelling, and other surface-finishing processes.

F. R. H. ALLON (John I. Thornycroft and Co., Ltd.), to study the methods of moulding, steelmaking, casting, heat-treatment, and testing of carbon and alloy steel castings in the U.S.A. and Canada.

K. W. J. BOWEN (Cambridge University), to study factors affecting the selection of materials for the construction of chemical and petroleum plant in the U.S.A. and Canada, with particular reference to the influence of research in this field.

M. G. GEMMILL (The United Steel Companies, Ltd.), to study in Britain and the U.S.A. the manufacture, testing, and application of steels for high-temperature service.

W. B. HALL (Nchanga Consolidated Copper Mines, Ltd., Northern Rhodesia), to study American and Canadian plant practice in the hydrometallurgy and electrowinning of base metals, with special reference to copper and its associate metals, and to make a general study of mechanization and plant management in ore-dressing and leaching plants.

MEETINGS

Annual General Meeting

The 81st Annual General Meeting took place on 26th and 27th April, 1950, at the Institute's offices, 4 Grosvenor Gardens, London, S.W.1. On the morning of the first day the retiring President, Sir Andrew McCance, LL.D., D.Sc., F.R.S., inducted the President-Elect, Mr. J. R. Menzies-Wilson, O.B.E., into the Chair, and the new President then delivered his Presidential Address on "*Iron Ore Resources and Open-Cast Operations in the Midland Orefield*" (*Journal*, 1950, vol. 165, June, pp. 129–137). A Buffet Luncheon was served in the Joint Library on both days, and a Members' Dinner was held at the Dorchester Hotel, Park Lane, London, on 27th April. The proceedings are recorded on pp. 135–140 of the *Journal* for February, 1951 (vol. 167).

The Centenary of the Birth of Sidney Gilchrist Thomas was marked by a special commemorative lecture by Mr. James Mitchell, C.B.E. (Honorary Treasurer), given at the Institute's offices on the evening of 26th April. The text will be found on pp. 1–8 of the *Journal* for May, 1950 (vol. 165).

Autumn Meeting

The Autumn Meeting was held at the Offices of the Institute on 15th and 16th November, 1950; The President (Mr. J. R. Menzies-Wilson, O.B.E.), was indisposed, and his place was taken by Dr. C. H. Desch, F.R.S. (Past-President) during the morning session, and by Mr. James Mitchell, C.B.E. (Honorary Treasurer) during the afternoon session on the 15th November. The proceedings will be recorded in a later issue of the *Journal*.

Special Meeting in Glasgow

At the invitation of The West of Scotland Iron and Steel Institute, a Special Meeting was held in Glasgow from 12th–15th September, 1950. The Rt. Hon. the Lord Provost of Glasgow (Mr. Victor D. Warren, M.B.E., T.D.) was the Patron, and a Reception Committee (Chairman, Sir Andrew McCance, LL.D., D.Sc., F.R.S.), an Executive Committee (Chairman, Mr. W. Barr), and a Ladies' Committee (Chairman, Lady McCance) were set up to make the arrangements. Mr. P. W. Thomas, Secretary of The West of Scotland Iron and Steel Institute, served as Honorary Secretary of the Meeting.

After Mr. W. Barr (President of The West of Scotland Iron and Steel Institute) had welcomed the visitors, a technical session was held jointly with that Institute; on that and the following days a large number of iron and steel works and engineering firms was visited, a banquet and receptions were held, and the meeting closed with a day's excursion on the Clyde.

The Council desire to express thanks on behalf of the Members and their Ladies to all those who helped to make the arrangements, including the Managements of the works visited, and their hosts at the various functions for the warmth of their reception.

A short account of the Meeting will be printed later.

Symposium on High-Temperature Steels and Alloys for Gas Turbines

Arrangements were made for a Symposium on the above subject to be held at The Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday and Thursday, 18th and 19th October, 1950. As the advance copies of the papers could not be prepared in time, owing to a dispute in the printing trade, the meeting had to be postponed. It has since been held on 21st and 22nd February, 1951, and an account will be included in the Council's next Annual Report.

FIFTH HATFIELD MEMORIAL LECTURE

Air Commodore Sir Frank Whittle, K.B.E., C.B., M.A., D.Sc., F.R.S., accepted an invitation to deliver the Fifth Hatfield Memorial Lecture, on "*Turbine Problems in the Development of the Whittle Engine.*" The Lecture was to have been held on 17th October, 1950, but was postponed when the date of the Symposium on High-Temperature Steels and Alloys for Gas Turbines (*see* above) was changed. The Lecture has since been given on 20th February, 1951, and an account will appear in the next Annual Report.

IRON AND STEEL ENGINEERS GROUP

The Engineering Committee, which organizes the activities of the Iron and Steel Engineers Group, was composed of the following (from May, 1950):

Chairman

Mr. C. H. T. WILLIAMS

Members

Mr. W. F. CARTWRIGHT	Mr. J. E. OWSTON
Mr. J. L. GASKELL	Mr. W. J. POOL
Mr. F. B. GEORGE	Mr. F. H. SANITER
Mr. W. M. LARKE	Mr. B. THORNTON
Mr. G. S. MARTIN	Mr. W. UDALL

Mr. P. WRIGHTSON

Ex-Officio

Mr. J. R. MENZIES-WILSON, O.B.E. (President)
Mr. JAMES MITCHELL, C.B.E. (Honorary Treasurer)
Mr. H. H. MARDON (British Iron and Steel Research Association)
Mr. I. S. SCOTT-MAXWELL (British Iron and Steel Federation)

Two full-day meetings, with buffet-luncheons, were

held at the Offices of the Institute on the undermentioned dates, for the discussion of the papers listed:

Thursday, 23rd March

"Traffic of Iron and Steel Works: A Method of Traffic Analysis," by H. H. Mardon and M. D. Brisby (1950, vol. 163, Dec., pp. 433–448).

"Traffic of Iron and Steel Works: The Application of Very High-Frequency Radio Communication," by H. H. Mardon, H. A. Chapman and M. D. Brisby (1950, vol. 164, Apr., pp. 425–438).

"Structural Frames for Melting Shops," by J. S. Terrington (1950, vol. 164, Feb., pp. 195–222).

"Proposed Method of Specifying Travel Motion Performance for Steelworks Overhead Cranes," by D. A. Wise and L. N. Bramley (1950, vol. 164, Apr., pp. 439–451).

Wednesday, 28th June

"Heating and Ventilation in the Iron and Steel Industry," by F. R. L. White (1950, vol. 165, June, pp. 221–225).

"Lighting in Iron and Steel Works," by G. W. Levey (1950, vol. 165, May, pp. 91–96).

"The Supply and Distribution of Water to Iron and Steelworks," by J. L. Daniel (1950, vol. 165, Aug., pp. 437–453).

The Meeting that was to have taken place in December was cancelled, since the papers intended for it could not be published in time, owing to the printing dispute.

A meeting of Junior Engineers was held at Ashorne Hill, Leamington Spa, on Wednesday and Thursday, 22nd and 23rd November. The object was to provide an opportunity for the younger engineers in the iron and steel and associated industries to discuss engineering problems of mutual interest. The following subjects were discussed:

"Organization and Steelworks Maintenance and the Layout and Equipment of Repair Shops."

"Training of Works Engineers."

On the evening of Wednesday, 22nd November, Mr. W. F. Cartwright delivered a Lecture on "The Steel Company of Wales, Ltd. Developments at Port Talbot."

PUBLICATIONS

The *Journal* was, as usual, published in twelve Monthly parts, comprising volumes 164 to 166; indexes and binding cases are being prepared.

Special Reports—No Special Reports were issued during the year.

Bibliographies—The following two Bibliographies were issued:

"Bibliography on the Occurrence of Nitrogen and Hydrogen in Liquid Steel (Covering the Period 1888–1949)." (*Bibliography* No. 16)

"Bibliography on the Physical Chemistry of the Electric Steelmaking Process." (*Bibliography* No. 17)

Translation Service—Translations of twenty-two foreign technical papers (Nos. 391–412) were issued during 1950. The charge was £1 each (10*s*. for each additional copy of the same translation). The Council wish again to thank those organizations and individuals who have kindly made translations available for inclusion in the Series.

A number of other translations, which were unsuitable for inclusion in the Series, were made for various Members at their own expense.

LIBRARY AND INFORMATION SERVICE

Joint Library

Every endeavour has been made to maintain and increase the usefulness of the Joint Library for the benefit of members. The expanding use made of the Library is shown by the large yearly increase in the number of publications borrowed since the libraries of the Institute of Metals and The Iron and Steel Institute were amalgamated. In 1939, the first complete year of the Joint Library, 4151 publications were sent out on loan; in 1946 the number was 7414, and in 1950, 11,060. During the year under review the Library has been enriched by the addition of 362 textbooks, and the Council take this opportunity to extend thanks on behalf of the Members to those authors and publishers who have made presentations to the Library.

Members are reminded that the use of the Lending Library is a valuable privilege of membership. Books and periodicals are sent post free to members resident in Great Britain. In addition to the books filed in the Joint Library, members may borrow through the Librarian, Mr. R. Elsdon, publications from the Science Library, the Institution of Civil Engineers, and the National Central Library. Assistance is also given to members in Great Britain and overseas to obtain photostat and microfilm copies of articles which can be supplied under certain conditions. Ninety-five photostat copies and 140 microfilms were supplied to members during the past year.

Information Service

The work of the Information Department is an important part of the service. The Department is prepared to answer enquiries concerning the scientific and technical literature from members, but it is not its function to give the type of advice which comes within the field of the metallurgical consultant.

EDUCATION

Joint Committee on Metallurgical Education (For the Year 1950)

The Joint Committee on Metallurgical Education completed the preparation of their recommendations on University Full-Time Degree Courses in Metallurgy. Copies were printed in booklet form and widely circulated to the Universities, Departments of Education, Examinations Boards and Councils and other National Educational Associations, Professional Institutions, and the Technical Press.

Joint Committee for National Certificates in Metallurgy (For the Year 1949–1950)

Three new Schemes for National Certificates in Metallurgy were approved; a number of Schemes for the Higher National Certificates are being organized in districts not yet covered.

Courses have been in operation at the following Technical Colleges:

Ordinary National Certificate (24): Battersea Polytechnic, London; Birmingham Central Technical College; The College of Technology, Bristol; Chesterfield Technical College; Corby Technical College; Coventry Technical College; Cumberland Technical College, Workington; Derby Technical College; Enfield Technical College; Leeds College of Technology; Llanelly Technical College, Carmarthenshire; Constantine Technical College, Middlesbrough; Neath Mining and Technical Institute; Newport Technical College, Monmouthshire; Nottingham and District Technical College; Rotherham College of Technology; Scunthorpe Technical College; Deeside Technical Institute, Shotton; The Chance Technical College, Smethwick; North Staffordshire Technical College, Stoke-on-Trent; Swansea Technical College; Wandsworth Technical College, London; County Technical College, Wednesbury; Wolverhampton and Staffordshire Technical College.

Contributory Centres (4): Bordesley Green Technical School; Moseley Grammar School Evening Institute, (Contributory Centres to Birmingham Central Technical College); Dudley and Staffordshire Technical College, (Contributory Centre to Wednesbury County Technical College); Nottingham People's College Senior Technical Institute, (Contributory Centre to Nottingham and District Technical College).

The above contributory centres provide the First Year of a Senior College, the Second and Third Years being completed at the main Colleges named.

Higher National Certificate (12): Battersea Polytechnic, London; Birmingham Central Technical College; Chesterfield Technical College; Coventry Technical College; Constantine Technical College, Middlesbrough; Rotherham College of Technology; Rugby College of Technology; Sir John Cass College, London; The Chance Technical College, Smethwick; Swansea Technical College; County Technical College, Wednesbury; Wolverhampton and Staffordshire Technical College.

Final Examinations for the Ordinary National Certificate were held at 20 Technical Colleges and for the Higher Certificate at 11 Technical Colleges.

Comparative figures of entries and successful candidates for the five years since the institution of the Scheme are as follows:

Ordinary National Certificate

		Number of Candidates	
Year	*Technical Colleges*	*Entered*	*Awarded Certificates*
1946	4	28	23
1947	11	102	69
1948	15	123	74
1949	21	222	107*
1950	20	281	143*

*(including 2 candidates whose Certificates were withheld in the previous year).

In 1950 the course for the Ordinary Certificate at Ilkeston has been transferred to Nottingham and District Technical College; and that for the Ordinary Certificate at Battersea Polytechnic to Wandsworth Technical College; at Leeds and Stoke-on-Trent Technical Colleges there were no candidates for the final examinations for 1950.

Higher National Certificate

		Number of Candidates	
Year	*Technical Colleges*	*Entered*	*Awarded Certificates*
1946	—	—	—
1947	2	22	18
1948	8	38	22
1949	10	74	59*
1950	11	62	42

*(including 9 candidates whose Certificates were withheld in the previous year.

32 candidates gained Distinctions in the final examinations held in 1950, having a final assessed percentage mark of 80% or over in one or more subjects; and prizes were awarded to 36 candidates. A total number of 128 prizes have been awarded during the five years of the Scheme.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The Institute continued to provide services for the British Iron and Steel Research Association, and the former close collaboration was maintained. The Institute's library, information, abstracting, and translation services are freely available to the Association, and member-firms may borrow books from the Library and use the information service without charge and in their own right. The *Journal* of the Institute is the principal medium of publication for the Association's reports on its researches; these papers, at the Association's request, receive the same scrutiny and treatment as other papers submitted to the Institute. The Institute also looks after certain matters of a more general character for the Association, such as educational activities, foreign relations, and sometimes the holding of conferences. Accounts of the Association's activities appear from time to time in the News Section of the *Journal*.

The Council are glad to record their appreciation of the close collaboration existing between the two organizations.

RELATIONS WITH OTHER SOCIETIES

The good relations between the Institute and other scientific and technical societies at home and abroad have been maintained. This applies particularly to the Institute of Metals and the Institution of Metallurgists. After the death of Dr. H. A. Dickie, Mr. W. C. Bell was appointed to succeed him as one of the Institute's representatives on the Council of The Institution of Metallurgists; the other representative is Mr. J. Sinclair Kerr. Collaboration with the Sheffield Metallurgical Association and the West of Scotland Iron and Steel Institute was maintained in the same way as before.

Affiliated Local Societies

There are ten Affiliated Local Societies, as follows:

Cleveland Institution of Engineers
Ebbw Vale Metallurgical Society
Leeds Metallurgical Society
Lincolnshire Iron and Steel Institute
Liverpool Metallurgical Society
Manchester Metallurgical Society
Newport and District Metallurgical Society
Sheffield Society of Engineers and Metallurgists
Staffordshire Iron and Steel Institute
Swansea and District Metallurgical Society

Under the scheme of affiliation the Institute and the Local Societies are able to be of mutual assistance, without in any way diminishing their complete freedom of action. The Local Societies admit Members of the Institute to their Meetings; the Institute pays to each Local Society a capitation grant of 5*s*. per annum for each Joint Member, and any of these who are Associate Members of the Institute pay a reduced annual subscription of £1 11*s*. 0*d*.

During the year under review five Local Societies organized Joint Meetings with the Institute: Swansea and District Metallurgical Society, 14th January and 9th December; Cleveland Institution of Engineers, 19th January; Manchester Metallurgical Society, 1st February; Ebbw Vale Metallurgical Society (with the Engineers Group of the Institute), 7th February, (with the Institute), 8th March, and (with the Engineers Group) 14th December; and Sheffield Society of Engineers and Metallurgists, 20th March.

Joint Meetings

On 2nd March, 1950, The West of Scotland Iron and Steel Institute organised a Joint Meeting with the Engineers Group of The Iron and Steel Institute. The lecture was entitled "*A Review of Recent American Rolling Mill Installations*," by Mr. A. J. Nussbaum.

The Joint Meeting with The West of Scotland Iron and Steel Institute on 12th September, 1950, during the Special Meeting in Glasgow of The Iron and Steel Institute, is referred to under "Meetings" on page 4.

On 21st November, 1950, the Sheffield Metallurgical

Association arranged a Joint Meeting with The Iron and Steel Institute, in Sheffield, to hear a lecture by Professor A. Preece on "*The Overheating of Steel.*"

Metallurgical Societies Overseas

During the year the Verein Eisenhütte Oesterreich (Austrian Iron and Steel Institute) was invited to become a "Kindred Society," of which bodies there are now eighteen:

American Institute of Mining and Metallurgical Engineers (Associate Member age limit, 33)
American Iron and Steel Institute
American Society for Metals
Association of Czechoslovak Mining and Metallurgical Engineers (Czechoslovakia)
Association des Ingénieurs sorti de l'Ecole de Liège (Belgium)
Associazione Italiana di Metallurgia (Italy)
Association Luxembourgeoise des Ingénieurs et Industriels (Luxemburg)
Australian Institute of Metals
Canadian Institute of Mining and Metallurgy
Indian Institute of Metals
Instituto del Hierro y del Acero (Spain)
Jernkontoret (Sweden)
Koninklyk Instituut van Ingenieurs (Holland)
Norsk Metallurgisk Selskap (Norway)
Société Française de Métallurgie (France)
Société Royale Belge des Ingénieurs et des Industriels (Belgium)
Verein Eisenhütte Oesterreich (Austria)
Verein Schweizerischer Maschinen-Industrieller (Switzerland)

Members of the Institute who are Members of, or are on the staffs of member firms of any of the above Societies, if resident in the countries concerned, pay the following reduced subscriptions to The Iron and Steel Institute: Ordinary Members, £3 13*s.* 6*d.*; Associate Members, £1 11*s.* 0*d.*

Representation at Meetings

Mr. Paul List represented the Institute at a Meeting of the Association Luxembourgeoise des Ingénieurs et Industriels on 15th April, which included a commemoration of Sidney Gilchrist Thomas.

Dr. C. H. Desch, F.R.S. (Past-President) and the Secretary represented the Institute at the centenary celebrations of the birth of Sidney Gilchrist Thomas organized by the Société des Ingénieurs Civils de France on 5th May, 1950. They also attended the centenary celebrations of the birth of Henry le Chatelier on 18th October, arranged by the Société Française de Métallurgie.

At the first General Meeting of the Verein Eisenhütte Oesterreich (Austrian Iron and Steel Institute) on 14th to 17th June, Mr. Howard Biers conveyed the Institute's good wishes to the newly constituted society.

The Institute was represented by Mr. W. C. F. Hessenberg (British Iron and Steel Research Association) at a Conference on Wire Ropes in Mines organized by the Institution of Mining and Metallurgy on 19th to 23rd September.

PRESENTATION TO THE INSTITUTE

One of the problems which the late Sir Henry Bessemer tried to solve was the provision of cabin accommodation on board ship which would remain steady in a rough sea. In his experimental ship, the S.S. *Bessemer*, completed in 1875, the cabin was suspended within the ship in such a way that when the hull rolled the cabin structure would not do so; the great length of the ship would take care of the pitching. Unfortunately the vessel proved to be both difficult to steer and expensive to run and was broken up. For many years the cabin was preserved complete in the garden of a house in the village of Hextable, Kent, but during the late war it was so badly damaged by bomb blast as to be irreparable. Through the courtesy of Mr. W. A. Woodward, one of the beautifully carved oak panels with which the interior of the cabin was embellished (the decoration was most ornate) has been presented to the Institute. The Council desire to express their best thanks to Mr. Woodward for the gift of this interesting souvenir.

HONOURS CONFERRED ON MEMBERS

The Council offer hearty congratulations to the many Members who have received honours or appointments during the year; their names have been recorded in the News of Members columns of the *Journal*.

FINANCE

(*The Accounts for* 1950 *are appended*)
(Figures for the previous year are printed in brackets for comparison)

General Fund

Income for the year ended 31st December, 1950, at £58,501 (£55,250) exceeded expenditure, at £52,603 (£53,415) by £5,898 (£1,835). This sum has been placed to General Reserve; it is likely to be partly required during the current year to meet unavoidable expenditure on external painting of the Institute's offices at No. 4 Grosvenor Gardens.

The reduction in expenditure was effected by further economies in Gross Salaries, which were £19,534 (19,801) —Net expenditure on Salaries, £18,174 (£18,516)—and in cost of Publications, £20,159 (£22,118), against which must be set increases in expenditure on the following headings:—National Insurance and Staff Superannuation Fund, £2,813 (£2,645); Administrative Expenses, £5,187 (£4,463); Library and Information Department, £1,197 (£929); Miscellaneous and Grants, £2,004 (£1,680).

The chief changes in income were in the following items: Subscriptions, £16,317 (£15,932); Publications, £33,350 (£30,079) and Companies' Special Subscriptions, £45 (£553); (these have now come to an end). The surplus on the Special Meeting in Glasgow, £663, has not been included in the year's income but has been transferred to General Reserve in the Balance Sheet.

The Publications Account shows that £12,726 (£6,790) has been contributed to the Institute's Income, as shown in Income and Expenditure Account of the General Fund, from the *Journal* Account and £323 (£997) from the Account for other Publications. In accordance with usual practice, expenditure on salaries and overheads has not been charged in the Publications Account.

Income, Expenditure, and Surplus on other Publications were less, since no new Special Reports were issued during the year. The reduction in expenditure on the *Journal*, £19,318 (£20,729) was largely due to the need to publish smaller issues during the autumn owing to the labour dispute in the printing industry. Advertisement Revenue, £22,692 (£18,932) and Sales, £5,475 (£4,874) showed satisfactory increases. Although small increases in these items, totalling about £1,000 to £2,000, may be expected during 1951, expenditure is likely to increase by substantially larger amounts, about £4,500 to £5,000, owing to very heavy increases in the cost of paper and probably also of printing. The need for continued economy is therefore apparent.

The Balance Sheet at 31st December, 1950, is presented in the usual form. The total of the Accumulated Fund, Life Composition Fund, and various Reserves and

Provisions, amounted to £40,044, compared with £33,301 a year previously; the comparable figure ten years ago at 31st December, 1950, was £33,691.

Trust Funds

Difficulty has frequently been experienced in recent years in expending the whole of the income of the Andrew Carnegie Trust Fund, owing to the few suitable applications for grants. This was again the case last year. Expenditure on grants was £478 (£1,561) and the total of the Accumulated Fund at 31st December, 1950, was £6,433 (£5,790).

Expenditure of the Williams Prize Fund was again £100 and the total of the Accumulated Fund £723 (£700).

The comparable figures for the Bessemer Medal Fund are: Income, £14; Expenditure, £4; total of Accumulated Fund, £32 (£22).

£60 was transferred from the Income and Expenditure Account of the Institute's General Fund to the Sir Robert Hadfield Medal Fund, as a contribution towards the cost of preparing a die for the Medal. Income, including this sum, was £68, expenditure £112, and the total of the Accumulated Fund £11 (£44). Expenditure included, in addition to the cost of preparing the die, the cost of three Medals awarded in previous years but not hitherto presented. This account is now shown separately instead of being included in the Balance Sheet of the General Fund as hitherto.

Investments

The total figures for investments of the General and Trust Funds at 31st December, 1950, were as follows:—Nominal Value, £83,642 (£83,642); Cost Value, as included in the Balance Sheets, £68,760 (£68,760); Market Value, £77,487 (£76,330).

THE IRON AND STEEL INSTITUTE

BALANCE SHEET, 31st DECEMBER, 1950

General Account

1949		LIABILITIES			1949		ASSETS		
£	£		£	£	£	£		£	£
		Accumulated Fund :			—		*Furniture and Fittings*	Not valued	
20,264		Balance as at 31st December, 1949	20,264		564		*Stock of Paper*		2,309
		Add Excess of Income over Expenditure for the year	5,808				*Investments at Cost per Schedule*		
		,, Surplus on Special Summer Meeting in Glasgow	663		28,010		(Market value at 31st December, 1950, £30,324)		28,010
				26,825					
		Reserve :					***Sundry Debtors and Payments in Advance :***		
		Entrance Fees Reserve :				5,919	Sundry Debtors	5,637	
	5,978	Balance as at 31st December, 1949		6,193		—	British Iron and Steel Research Association	697	
5,978						354	Current Accounts	283	
		Current Liabilities and Provisions :				598	Deposits and Payments in Advance	1,098	
	5,157	Sundry Creditors (part estimated)	6,193		6,871				7,715
	1,510	Due to Life Composition Fund	1,692		242		*Cash in Hand and at Bank*		5,915
	44	Due to Sir Robert Hadfield Medal Fund	11		265		*Joint Committee on Metallurgical Education*		29
	22	Due to Bessemer Medal Fund	32						
	329	Due to Andrew Carnegie Research Fund	14						
	309	Subscriptions in Advance	190						
	239	Payments received in advance for Publications	943						
		Sundry Provisions as at 31st December, 1949 :							
	600	Reserve for Ten Year Index	600						
	500	Library Account	500						
	1,000	Repairs, Decorations, and Equipment	1,000						
	2,100			2,100					
9,710				11,175					
£35,952				£43,978	£35,952				£43,978

Special Funds

1949					1949				
£			£	£	£			£	£
		Life Composition Fund :					*Life Composition Fund :*		
		Balance as at 31st December, 1949	4,959		4,959		Investments at Cost as per Schedule	3,449	
4,959		*Add* Compounded during 1950	182				(Market value at 31st December, 1950, £4,083)		
				5,141	—		Due from General Fund	1,692	
									5,141
£40,911				£49,119	£40,911				£49,119

We have examined the above Balance Sheet of the Institute and found it to be correct.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET,
LONDON, E.C.2
March 7th, 1950

(*Signed*) W. B. KEEN & CO.,
Chartered Accountants

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1950

EXPENDITURE

1949			£	£	£
		Staff Expenses :			
	19,801	Salaries	19,534		
		Less Contributions from :			
		Andrew Carnegie Research Fund	150		
		Institute of Metals	100		
		Institution of Metallurgists	60		
		Joint Committee on Metallurgical Education ...	300		
		Joint Committee for National Certificates in Metallurgy	500		
		Mond Nickel Fellowships Committee	250		
	1,285		1,360		
18,516				18,174	
	358	National Insurance		336	
	2,287	Staff Superannuation Fund		2,477	
21,161		Total Staff Expenses			20,987
		Other Administrative Expenses :			
	1,049	Printing and Stationery		1,065	
	456	Postage and Receipt Stamps		572	
	1,026	Travelling and Entertainment : General		1,225	
	728	Advertising		963	
	361	Meetings		515	
	399	Telephones and Telegrams		376	
	52	Insurances		78	
	147	Audit Fee—1949		147	
	245	Sundry Payments		246	
4,463					5,187
		Establishment Expenses :			
	1,200	Rent		1,200	
	1,463	Cleaning, Heating, Lighting, and Water		1,446	
	865	Repairs and Decorations	286		
	628	*Less* Transfer from Reserve			
	237			286	
	337	Office Furniture and Fittings	138		
	181	*Less* Transfer from Reserve			
	156			138	
3,056					3,070
		Publications : (*See* Publications Account)			
	20,729	1950 *Journal* : Printing, Paper, etc.		19,318	
	1,137	Other Publications : Printing and Paper		609	
	252	Translations : Preparation		232	
22,118					20,159
50,798		*Carried Forward*			49,403

INCOME

1949			£	£
	50	*Entrance Fees*	—	
	50	*Less* Transfer to Reserve	—	
—	—			—
		Subscriptions :		
	15,547	Current	15,764	
	17	Companies' Nominations	—	
	368	Arrears	553	
15,932				16,317
	570	*Companies' Special Subscriptions*	45	
	17	*Less* Transfer to Subscriptions Account	—	
553				45
		British Iron and Steel Research Association :		
6,000		Block Grant for Services other than Publications		6,000
		Interest on Investments (Gross) :		
	1,072	General Fund	1,089	
	141	Life Composition Fund	141	
1,213				1,230
		Institute of Metals :		
	850	Rent and Services	850	
	500	Library	500	
1,350				1,350
123		*Sundry Receipts*		142
		Special Summer Meeting in Norway :		
	834	Excess of Income over Expenditure	—	
	834	*Less* Transfer to Accumulated Fund	—	
—	—			—
		Special Meeting in Glasgow :		
		Excess of Income over Expenditure	663	
		Less Transfer to Accumulated Fund	663	
—				—
		Publications : (*See* Publications Account)		
		1950 *Journal :*		
	27,519	Revenue from Advertisements, Sales, and Amounts payable by British Iron and Steel Research Association	32,044	
	2,134	Other Publications—Sales and Payments by British Iron and Steel Research Association	932	
	426	Translations—Sales	374	
30,079				33,350
55,250		*Carried Forward*		58,434

£	£		£	£	£
50,798		*Brought Forward*		49,403	55,250
		Library and Information Department :			
	613	Library : Books and Binding	769		
	94	Book Reviewers' Fees	49		
	322	Abstractors' Fees	379		
929				1,197	
		Miscellaneous :			
	1,147	Historical Investigator : Honorarium and Expenses	1,240		
	228	Contributions to Affiliated Local Societies	182		
		Education :			
	125	Joint Committee for National Certificates in Metallurgy ...	150		
	50	Joint Committee on Metallurgical Education	50		
	25	Mond Nickel Fellowships Committee	200		
		List of Members	250		
		Grants :			
	1	Joint Committee for Materials and their Testing	1		
	25	British Standards Institution	25		
	10	Mellor Memorial Fund	—		
	16	Parliamentary and Scientific Committee	16		
	10	Sheffield University Foundry Prize	—		
	38	British Ceramic Research Association	25		
	5	Association of Libraries and Information Bureaux ...	5		
	—	Sir Robert Hadfield Medal Fund	60		
1,680			—	132	
				2,004	
8		*Adjustments for* 1948		—	
1,835		Excess of Income over Expenditure		5,897	
£55,250				£58,501	£55,250

£	£		£	£
		Brought Forward		58,434
		Adjustments for 1949 :		
		Amounts overprovided : Indexes	139	
		Bound Volumes	30	
			169	
		Less amounts underprovided : Binding Cases	102	
				67
				£58,501

PUBLICATIONS ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1950

1950 *Journal*

1949 £	£	EXPENDITURE	£	£	1949 £	£	INCOME	£	£
	16,491	Printing, Paper, and Blocks : Text and Advertisements	15,072			18,932	Advertising Revenue		22,692
	255	Bound Volumes (estimated)	250			3,113	Sales : *Journal*—1950 Monthly Journal and Bound Volumes ...	3,538	
	675	Index (estimated)	600			1,064	*Journal* Back Numbers	923	
	548	Binding Cases (estimated)	250			697	Reprints and Blocks	1,014	
	2,254	Packing and Postage	2,456			4,874			5,475
	506	Reprints	690			3,713	Amounts payable by British Iron and Steel Research Association ...		3,698
20,729				19,318			Binding Cases		179
6,790		Balance transferred to Income and Expenditure Account		12,726					
£27,519				£32,044	£27,519				£32,044

Other Publications

£		EXPENDITURE	£	£	£	INCOME	£
	—	Bibliographies	363		2,134	Sales and payments by British Iron and Steel Research Association ...	932
1,137		Special Reports	246				
997		Balance transferred to Income and Expenditure Account		609			
				323			
£2,134				£932	£2,134		£932

ANDREW CARNEGIE RESEARCH FUND

BALANCE SHEET, 31ST DECEMBER, 1950

1949		LIABILITIES		
£	£		£	£
		Amount of Original Fund, $100,000	21,241	
		Add Amount Capitalized per last Balance Sheet	4,596	
25,837				25,837
		Sundry Creditors:		
	963	Grants	585	
	10	Auditors' Fees	10	
973				595
2,600		Reserve for Travelling Scholarships		2,600
5,790		Accumulated Fund—Balance per Account annexed		6,433
£35,200				£35,465

1949		ASSETS		
£	£		£	£
33,963		Investments at Cost per Schedule (Market value at 31st December, 1950—£39,062)		33,963
		Balances at Bank:		
	197	On Current Account	764	
	9	On Deposit Account	9	
	548	Post Office Savings Banks	561	
754				1,334
154		Income Tax Recoverable		154
329		Iron and Steel Institute: Current Account		14
£35,200				£35,465

ACCUMULATED FUND, 31ST DECEMBER, 1950

£			£
1,561		Grants	478
150		Contribution to General Fund on account of Salaries	150
10		Audit Fee	10
—		Sundry Expenses	16
5,790		Balance carried forward	6,433
£7,511			£7,087

£	£		£	£
6,214		Balance at 31st December, 1949		5,790
		Income for the Year ended 31st December, 1950:		
	1,284	Interest on Investment (Gross)	1,284	
	13	Interest on Deposits	13	
1,297				1,297
£7,511				£7,087

WILLIAMS PRIZE FUND

BALANCE SHEET, 31ST DECEMBER, 1950

1949		LIABILITIES		
£	£		£	£
2,220		Capital Value representing Market Value of £3,000 3½% Conversion Loan on 21st September, 1926, when the Fund was inaugurated		2,220
26		Sundry Creditor—Iron and Steel Institute		—
700		Accumulated Fund—Balance per Account Annexed		723
£2,946				£2,943

1949		ASSETS		
£	£		£	£
2,670		£3,452 15*s.* 7*d.* 3½% Conversion Loan (at cost) (Market Value at 31st December, 1950—£3,315)		2,670
		Balance at Bank:		
	271	On Current Account	116	
	5	Post Office Savings Bank	157	
276				273
£2,946				£2,943

ACCUMULATED FUND, 31ST DECEMBER, 1950

£		£
100	Awards	100
700	Balance carried forward	723
£800		£823

£	£		£	£
679		Balance at 31st December, 1949		700
		Income for year ended 31st December, 1950:		
121		Interest on 3½% Conversion Loan	121	
		Interest on Post Office Savings Bank Account	2	
				123
£800				£823

BESSEMER MEDAL FUND

BALANCE SHEET, 31ST DECEMBER, 1950

£	LIABILITIES	£	£	ASSETS	£
	Capital Value representing Market Value of £400 4% Debentures of L. & N.W.		400	£474 15*s.* 0*d.* British Transport 3% Guaranteed Stock 1978/88	400
400	Railway	400		(Market Value at 31st December, 1950—£433)	
22	Accumulated Fund—Balance per Account Annexed	32	22	Sundry Debtors—Iron and Steel Institute	32
£422		£432	£422		£432

ACCUMULATED FUND, 31ST DECEMBER, 1950

£		£	£		£
4	Medal	4	12	Balance at 31st December, 1949	22
22	Balance carried forward	32		Income for year ended 31st December, 1950:	
			14	Interest on British Transport Stock	14
£26		£36	£26		£36

SIR ROBERT HADFIELD MEDAL FUND

BALACE SHEET, 31ST DECEMBER, 1950

1949 £	LIABILITIES	£	1949 £	ASSETS	£
	Capital Value representing the Market Value of £267 11*s.* 2*d.* 3% Savings Bonds		268	£267 11*s.* 2*d.* 3% Savings Bonds 1955/65	268
268	1955/65	268		(Market Value at 31st December, 1950 – £270)	
44	Accumulated Fund—Balance per Account Annexed	11	44	Sundry Debtor – Iron and Steel Institute	11
£312		£279	£312		£279

ACCUMULATED FUND 31ST DECEMBER, 1950

£		£	£		€	£
	Medal	13	36	Balance at 31st December		44
	Cost of Die for Medal	88		Income for Year ended 31st December, 1950:		
44	Balance carried forward	11		Interest on 3% Savings Bonds	8	
			8	Grant from Iron and Steel Institute	60	
						68
£44		£112	£44			£112

THE IRON AND STEEL INSTITUTE

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1950
SHOWING NOMINAL VALUES, COST AND PRESENT MARKET VALUES

Nominal Value	Nature of Security	Market Value, 31st December, 1950	Cost Value
	GENERAL FUNDS OF THE INSTITUTE		
£ s. d.		£	£
2,197 7 0	3½% War Stock	2,065	2,161
1,324 7 4	3½% Conversion Loan	1,271	1,254
2,954 1 0	4% Consolidated Stock	3,020	3,176
12,242 19 3	4% Funding Loan, 1960/90	13,100	9,512
1,000 0 0	3% Defence Bonds (P.O. Register)	1,000	1,000
2,000 0 0	3% Savings Bonds, 1955/65	2,020	2,000
2,000 0 0	Do. 1960/70	1,970	2,000
1,500 0 0	Do. 1965/75	1,448	1,500
4,854 2 0	British Transport 3% Guaranteed Stock, 1978/88	4,430	5,407
		£30,324	£28,010
	LIFE COMPOSITION FUND		
587 13 10	3½% Conversion Loan	564	513
205 15 6	3½% War Stock	193	212
681 13 0	4% Funding Loan	729	600
196 10 1	Do.	210	231
2,615 11 2	British Transport 3% Guaranteed Stock, 1978/88	2,387	1,893
		£4,083	£3,449
	ANDREW CARNEGIE RESEARCH FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton and N. H. Rollason)		
6,897 14 11	3½% War Stock	6,484	6,896
800 0 0	Do.	752	794
2,693 12 0	3½% Conversion Loan	2,586	2,007
3,922 14 10	2½% National War Bonds, 1951/53	3,961	3,998
1,793 15 0	British Electricity 3% Guaranteed Stock, 1968/73	1,731	1,762
2,166 18 7	4% Funding Stock, 1960/90	2,319	2,643
500 0 0	2½% Defence Bonds (P. O. Register)	500	500
1,250 0 0	3% Defence Bonds (P. O. Register)	1,250	1,250
17,812 10 3	British Transport 3% Guaranteed Stock, 1978/88	16,253	10,863
1,000 0 0	3% Savings Bonds, 1955/65	1,010	1,000
2,250 0 0	Do. 1960/70	2,216	2,250
		£39,062	£33,963
	WILLIAMS PRIZE FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton, and N. H. Rollason)		
3,452 15 7	3½% Conversion Loan	£3,317	£2,670
	SIR ROBERT HADFIELD MEDAL FUND		
267 11	3% Savings Bonds, 1955/65	£270	£268
	BESSEMER MEDAL FUND		
	(Trustees: Desmond Lysaght, The Hon. R. G. Lyttelton, and N. H. Rollason)		
474 15 0	British Transport 3% Guaranteed Stock, 1978/88	£435	—

(*Signed*) J. MITCHELL, *Hon. Treasurer*

(*Signed*) K. HEADLAM-MORLEY, *Secretary*

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the balances at the Bankers and the Securities for the Investments shown above.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET, E.C.2
March 7th, 1951

(*Signed*) W. B. KEEN & Co.,
Chartered Accountants

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

ANDREW CARNEGIE RESEARCH REPORT

The Evaluation of Macroscopic Residual Stresses in Cylindrical Bars

By H. Föppl, Dr. Ing.

SYNOPSIS

The basic assumptions for the classification and calculation of residual stresses are discussed. Some recent advances in the theory of the straining of materials are considered which can be used in obtaining the limiting values of residual stresses at each local point in a body. A simplified idea is introduced to describe the plastic deformations which cause residual stresses. This includes an intermediate layer between the surface and the core in which a 'stress reversal' takes place. Theories of stress reversal are confirmed by results calculated from new equations. These results are compared with results calculated from Heyn's and Sachs' equations. It is shown that all the stresses can be calculated accurately, even if the strains are measured in only one direction. This is made possible by the introduction of strain ratios by which the relationship of the strains in the principal axes are expressed. Stress reversal implies a discontinuity in the gradual transition from the plastic deformation of the surface to the purely elastic deformation of the core, for example, in a shot-peened bar. It was therefore ascertained from the experiments that a mainly bi-axially stressed surface layer can behave independently of the tri-axially stressed core of the specimen.

A STATE of residual stress present in a body occurs in the absence of any external forces, and is due to differential strains acting between small elements of the body. Bodies are often inhomogeneously deformed during processing, and this results in single elements being altered in shape and size. The two basic examples of local deformations are shown diagrammatically in Fig. 1. An element *a* may change its shape to that of element *b* by plastic deformation, and an element *c* may increase in size to that of element *d* by alteration of volume. Parts of the body in the neighbourhood of elements *b* and *d* resist these deformations by adapting themselves elastically. Thus stresses are caused in the neighbourhood of *b* and *d*. At the same time, stresses of opposite sign are effective in the elements *b* and *d*. The stresses which are thus generated are residual if elements *b* and *d* are permanently altered, and can be determined if the whole body is strained by a measurable amount. The strains become measurable if many such elements *b* and *d* with similar deformations are added up, *e.g.*, in the surface of a body or in a zone of the interior. This paper is concerned only with those residual stresses that can be observed on a macroscopic scale. It is assumed that the material is homogeneous and quasi-isotropic.

Three main causes of residual stresses can be considered. In the first place, there are stresses which are generated by misfit. (Such misfit occurs, for example, in welds where portions of bodies are at different temperatures when they are joined, and residual stresses are generated by differential contractions on cooling.) Secondly, local volume changes can be brought about by chemical and physical

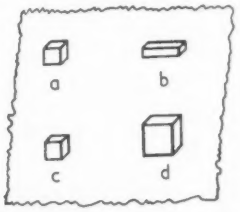

Fig. 1—The alteration of shape and size of single elements in a material

transformations, and these can produce residual stresses, *e.g.*, in the nitriding of steel, or in the formation of martensite in a steel. Thirdly, plastic deformations caused by local overloading by external forces can also produce residual stresses. An example of

A report, received 15th March, 1950, on a research carried out with the aid of a grant from the Andrew Carnegie Research Fund.

Dr. Föppl is in the Department of Metallurgy at Cambridge University.

this is the plastic deformation of surfaces by shot-peening or surface-rolling, to both of which this paper relates particularly.

BASIC ASSUMPTIONS

The determination of residual stresses is based upon two fundamental assumptions : the equilibrium of the stresses inside a body, and the continuity of the deformed material. The conditions of equilibrium are such that any residual tensions in one part of the body are balanced, in each principal axis, by compressions acting in the surrounding elements. Furthermore, the total strains in the three principal axes must be compatible, and the continuity of the material is secured by this fact. By total strains is meant the sum of the permanent and the elastic strains, and it should be noted that these parts of the total deformation do not usually have the same principal axes and are not in themselves compatible. Therefore, either the permanent or the elastic deformations must be measured independently to determine the residual stresses. However, as mentioned above, the distribution of the residual stresses that is connected with the elastic deformations must satisfy the conditions of equilibrium.

If a body containing residual stresses is cut the stresses are released, and the cut portions no longer fit perfectly together. From the changes of dimensions which occur on cutting, and by using the laws of elasticity, it is possible to calculate the magnitude of the initial residual stresses. In practice it is usual to cut a small amount at a time from the body, and to measure, after each cut, the changes in dimension of the uncut portion.

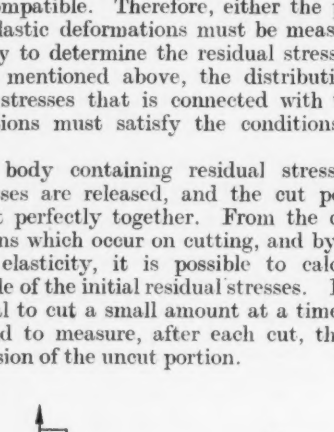

Fig. 2—Measured strains after boring-out or removing surface layers

There are two possible ways of measuring the residual stresses :

(i) The elastically deformed parts can be destroyed, retaining the permanently deformed parts. The length changes related to the thickness cut off the cross-section are represented by a hyperbola (Fig. 2*a*). Thus, for example, one obtains a hyperbola by boring-out a surface-rolled cylindrical bar, as long as the boring-out is limited to the purely elastically deformed core. If the plastically deformed parts also are cut away by the boring-out process, the curves $e_r = f_1(r)$ and $e_a = f_2(r^2)$ depart from the hyperbola. O. Föppl[1] described a method for calculating the residual stresses from the hyperbolas, with the simplification that Poisson's ratio is assumed to be zero. This method allows the calculation of the stresses to be made from the relatively high strains that occur when the plastically deformed layers of a surface-compressed bar are stress-relieved by boring-out the elastic core.

(ii) The other possibility is to destroy, step by step, the plastically deformed parts of the body, until only the elastically deformed part is retained. In this case, if all the plastically deformed layer is equally deformed, a straight line is obtained instead of a hyperbola (Fig. 2*b*). The stresses can be calculated from the shapes of the curves, which depart from a straight line if the plastic deformation is inhomogeneous. The measured strains must be determined more accurately in this case, as they are not so great as in method (i). An important advantage of this method, however, is that the remaining elastically unstressed body must have exactly the same dimensions after cutting away the plastically deformed layer as before the production of the residual stresses. The author's experiments described in this paper are based on the second method.

If a portion of a body is plastically deformed by local external forces, this may be termed primary plastic deformation. All plastic deformations that are initiated later by the external forces together with the residual stresses can be termed secondary plastic deformations. These secondary plastic deformations are independent of the mode of origin of the residual stresses, and occur when the residual stresses overcome the ability of the material to resist them elastically. This often happens during the production of residual stresses at a point between the surface and the interior of a body, and very inhomogeneous straining of the material takes place. In connection with the inhomogeneous straining, the present state of the theory of the straining of metals should be considered.

RECENT IDEAS ON THE STRAINING OF MATERIALS

Up to the present, the straining of materials has usually been interpreted in terms of Coulomb-Guest-Mohr's maximum shearing-stress theory, or of the shear-strain energy hypothesis of Huber and von Mises. The shear-strain energy hypothesis gives more accurate values for the actual straining of isotropic materials, and therefore determines more accurately the point at which the elastic limit is exceeded and plastic flow begins. The beginning

of plastic flow depends also on the mean normal stress, which is taken into account in the shear-strain energy hypothesis, in contrast to Mohr's theory in which it is neglected. By numerous experiments Roš and Eichinger[2] and other authors have confirmed the shear-strain energy hypothesis for metals. According to Roš, the straining is determined by the constancy of the so-called resultant stress, which is related to the resultant strain by the expression $e_{res} = f(\sigma_{res})$. This presentation is a satisfying approach to the real values of strain in an isotropic material under a multiaxial state of stress. The straining of non-isotropic material can best be described by the maximum shear-stress criterion; Hill[3] has developed for non-isotropic material a theory of straining which is in agreement with the behaviour of heavily deformed steel.

Owing to involved design shapes, which necessitate variations in cross-section and the presence of fillets, keyways, notches, etc., and also to the production of residual stresses for beneficial purposes in engineering parts, materials are inhomogeneously strained, particularly at the point between the surface and the core. Experiments of Roš[4] have shown the dependence of the straining of materials upon the stress gradients. Roš pointed out that to be able to compare different states of stress with one another, these gradients must be kept constant. Siebel[5, 6] considered the degree of inhomogeneity in the distribution of the stresses, for a determined value of plastic deformation, at the place of the highest strain. He obtained from this deformation a comparative value in the form of a maximum safety stress, which includes the influence of inhomogeneity in the distribution of the stresses.

Theories such as those mentioned above are needed to describe the inhomogeneous straining of the material in the layer between the bi-axially stressed surface and the tri-axially stressed core in a bar which contains residual stresses. This layer may be termed the intermediate layer.

PLASTIC DEFORMATION OF THE INTERMEDIATE LAYER

It is generally considered sufficient to describe the fundamental facts relating to a state of residual stress in a cylindrical bar (*e.g.*, shot-peened), by separating the body into a plastically deformed surface layer *S* and an elastically deformed core *K* (*see* Fig. 3*a*). If compression stresses are created in the layer *S* by the plastic deformations, the tension stresses of the core *K* must balance them. However, from experiments described later it can be shown that the division into elastically and plastically deformed parts is not accurate enough to describe the deformations which actually occur. Another layer is formed between the plastically deformed surface layer *S* and the elastically deformed core *K*. The plastic deformation of this layer has an opposite sign to that of the elastic deformation of the core. The layers of a surface-compressed cylindrical bar are shown in Fig. 3*b*, after stress-relieving by cylindrical cutting. As in Fig. 3*a*, a core *K*, which was only elastically deformed, and a plastically deformed surface layer *S*, which initiates the residual stresses, can be seen.

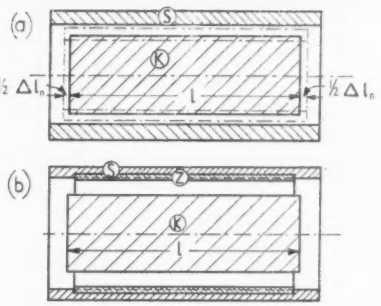

Fig. 3—Representations of a surface-rolled cylindrical bar. (*a*) Standard scheme; (*b*) improved scheme incorporating intermediate layer *Z*

The intermediate layer *Z* is plastically shortened; the diameter, however, is increased in both layers, that of the layer *Z* more than that of the layer *S*. The parts *S* and *Z* of the body, as shown in Fig. 3*b*, overlap slightly in the stress-relieved state. The reason for this shape of plastic deformation of layer *Z* has not been ascertained. However, it must be assumed that the stresses that were effective in this layer during the plastic deformation of the layer *S* did exceed the elastic limit of the material.

RESULTS FROM PUBLISHED EXPERIMENTS

The residual stresses of cylindrical bars can be divided into those of three zones, in the same way as the plastic deformations from which they arise. These are the surface *S*, the core *K*, and an intermediate layer *Z*. Layer *Z* is subjected to a change of stresses which may be termed stress reversal. The stress reversal is caused by the plastic deformation of the layer *Z*, and therefore has always been obtained between the tension or compression stresses in the surface and the opposite stresses of the core. The stress reversal is situated in a zone of the body in which a tri-axial state of stress is present. The more the stresses become equal in the three axes, the less are the measurable deformations. It is not possible, therefore, to determine the stresses in this

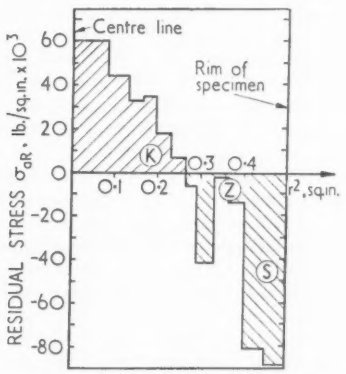

Fig. 4—Longitudinal residual stresses obtained by quenching a 1⅛-in. dia. nickel–chromium bar (Austin[10])

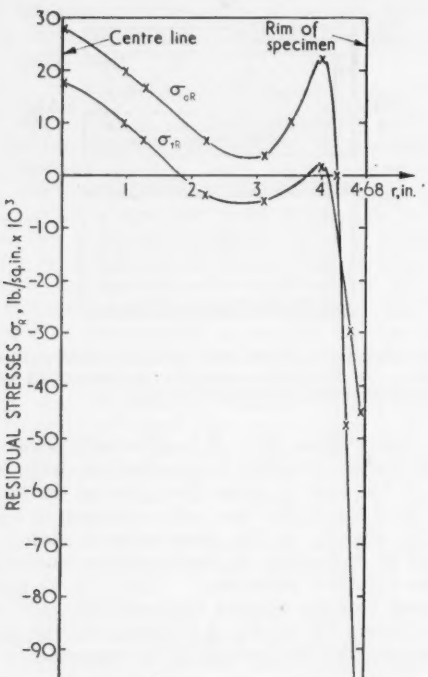

Fig. 5—Residual stresses in full-size crank pins (Horger[14] and Timoshenko[15])

zone accurately enough, with the available experimental methods, to say whether or not they are dangerous.

The works of numerous researchers[7–16] dealing with the determination of residual stresses show a stress reversal in the intermediate layer of cylindrical bodies, instead of a homogeneous change from a positive to a negative value. No consideration, however, is given to this effect. The residual stresses that were determined in these papers were generated in quite different ways. In some cases measurements were obtained on cold-worked or heat-treated specimens, and in others surface-compressed specimens were used. All specimens used were of cylindrical shape.

Residual stresses, which were found by Austin[10] during a determination of the stress distribution in hardened specimens, using Heyn's method, are shown in Fig. 4. Between the outer zone S and the inner zone K is the intermediate layer Z, in which the stress reversal has taken place. Curves of similar shape are to be found in papers by Heyn[7] and other authors.[11, 17]

Measurements obtained by Horger[14] and Timoshenko[15] from surface-rolled locomotive crank pins are shown in Fig. 5. The strains were obtained by a boring-out technique, and the stresses were calculated from Sachs' formulæ. The results show no elastically deformed core in the centre cross-section of the axles. This means that, if these stress distributions are accurate, the plastic deformation must have taken place up to the centre of the axles. However, it must be assumed that only the surface of the specimens was plastically deformed, as the surface-rolling was carried out by strong but locally limited impressions of a small roller. If, however, the core was only elastically deformed, the stresses must have been constant in this region, as pointed out by O. Föppl.[18, 19] Thus it follows that Sachs' formulæ give inaccurate values towards the centre of the bored-out cross-section. These formulæ are derived on the assumption of a bi-axial state of stress. The actual state of stress departs the more from this the smaller the borehole of the cylinder. In applying these formulæ, therefore, it must be considered that inaccurate values of the stress distribution are obtained at the beginning of the boring. If the borehole is enlarged, the radial stresses become smaller and the formulæ become more accurate. The formulæ are therefore valid only for ring-shaped cross-sections in which the radial stress can be neglected. However, the stress reversal near the surface can be seen to be well defined.

SOME RECENT EXPERIMENTS

The present author has determined residual stresses in cylindrical specimens 8 in. long × $\frac{3}{8}$ in. dia., using a method outlined in the Appendix; full details of this method have been published in the *Mitteilungen des Wöhler-Instituts*.[20] The specimens were manufactured from Si–Mn spring steel B.S. En 45, and after hardening were tempered to 470 Brinell. The specimens were carefully finished all over, and were fine-ground on the ends. Length changes Δl could be measured accurately up to $\pm 0{\cdot}1$ micron (4×10^{-6} in.) by comparing the length l of each specimen with a standard comparison specimen.

After initial measurements had been made, for the difference in length between the specimen and the comparison specimen, the specimens were shot-peened. The shot-peening was carried out with an intensity equal to that which is used for commercial springs of equal hardness. The ends of the specimens were protected against impinging blast by thick pieces of steel. The specimens were measured again after the shot-peening, when the specimen and the standard bar had the same temperature. The total elongation of the specimens amounted to about 60 microns. The elongation is the same as the elastic elongation of the core. As the elastically deformed core has a far greater cross-section than the plastically deformed surface layer, the total elongation of the specimen is considerably smaller than the elastic compression of the plastically deformed surface. The surface layer is elongated by a multiple of this amount during the plastic deformation. It is because of the connection of the core with the surface that the plastic elongation of the surface layer is elastically diminished to nearly the original length of the stress-free body. The core becomes longer by the small amount that was measured as the elongation of the whole specimen after the production of the residual stresses. The elongation of the specimen will be diminished again if the plastically deformed layer is removed by etching.

In the experiments, the etching was carried out in eleven steps, and a curve was obtained relating the

contraction in length of the specimens to the thickness of the layer removed (Fig. 6). In the first section of the curve, up to a depth of etching of about 0·006 in., the shortening Δl of the core by etching away the outer layer rises linearly with the thickness of the layer removed. The more the interior is penetrated by etching, the smaller are the changes in length of the specimen with the thickness of the layer etched away. If all the plastically deformed layer is etched away, the curve must approach gradually to a horizontal line. The etching curves obtained by the earlier experiments of the author,[20] of the type of that of Fig. 6, were assumed to reach a maximum without passing through a stage having a negative value for the tangent to the curve. In the earlier experiments the length of the core, which after surface rolling had increased by the amount Δl_n, diminished, after the etching away, by an amount $\Delta l_o = -\Delta l_n$, without becoming less than the original length. According to the new experiments, the curve (Fig. 6) passes a maximum point and then gradually approaches the horizontal. This can be observed only if the layers which are removed are of completely uniform thickness. The earlier tests of the author were not accurate enough to show up this feature of the curve.

An improved measuring device and a more accurate measuring gauge have been used in the new tests (*see* Fig. 9). The diameter of the specimens has been decreased by 80% (to $\frac{3}{8}$ in.), the length remaining unchanged. In this way the accuracy of the measurements has been increased. Decreasing the diameter $2r$ of the specimens while maintaining the same length l means that the influence of the warping of the front surfaces on the results of the measurements is considerably decreased. These warping effects could therefore be neglected in the measurements. (It was assumed that all fibres retain the same length.) The warping in the neighbourhood of the front surfaces cannot spread very far in the interior of the specimens when the length is about twenty times the diameter, and the error is therefore negligible. To simplify the method of calculation it has been assumed that the end effect can be observed.

As a method of producing local plastic deformations, surface rolling is more effective than shot-peening. There is, however, a difference in the deformation in each case. Shot-peening produces circular impressions, and the timing is completely random, so that there is no marked tendency for the strains to occur preferentially in the axial direction. Nevertheless, greater percentage elongations are, in fact, produced in the axial direction during the shot-peening of surfaces of cylindrical specimens. The bars become longer and thinner.

By surface-rolling, elliptic impressions are produced in the surface, owing to the shape of the roller. The material yields, therefore, more in the axial than in the tangential direction. The material is pushed before the tool as the impressions follow one after another, so that the axial direction of flow is preferred, rather than the tangential direction. The percentage elongation of the surface layer in the axial direction is about three times as great as in the tangential direction. The ratio of the tangential and axial surface strains is therefore small; this was shown previously by the author, by tests on a surface-rolled sheet.[20]

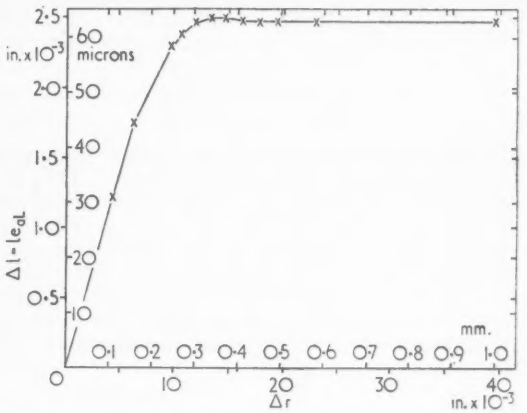

Fig. 6—Length changes, Δl, of shot-peened bar, obtained by etching away the cylindrical surface. Diameter of bar = $\frac{3}{8}$ in. (9·55 mm.); length = 7·6 in. (190 mm.)

CALCULATION OF RESIDUAL STRESSES

The residual stresses are calculated from the strains in the principal axes, using Hooke's Law. In the resulting stress-strain formulæ, the stresses σ and strains ε are distinguished by two subscripts, the first denoting the direction (a axial, t tangential, or r radial), the second indicating the location of the stresses or strains as belonging to the surface layer S, or the core K. It is assumed that the surface is stressed only in two dimensions. Accordingly, the appropriate stress-strain relations are :

$$\varepsilon_{aS} = \frac{\sigma_{aS}}{E} - \frac{\sigma_{tS}}{mE} \quad \text{.....(1)}$$

$$\varepsilon_{tS} = \frac{\sigma_{tS}}{E} - \frac{\sigma_{aS}}{mE} \quad \text{.....(2)}$$

The core is stressed in three dimensions, but since the stresses in radial directions are equal, the radial stress occurs with a factor 2 in the stress-strain relations :

$$\varepsilon_{aK} = \frac{\sigma_{aK}}{E} - \frac{2\sigma_{rK}}{mE} \quad \text{.....(3)}$$

$$\varepsilon_{rK} = \frac{\sigma_{rK}}{E} - \frac{\sigma_{rK} + \sigma_{aK}}{mE} \quad \text{.....(4)}$$

for the core.

Solving equations (1) and (2) for ε_{aS} and ε_{tS} gives the stresses in terms of the strains. For the two-dimensional case, the stress is given by :

$$\sigma_{aS} = E \cdot \frac{m^2}{m^2 - 1}\left\{\varepsilon_{aS} + \frac{\varepsilon_{tS}}{m}\right\} \quad \text{.....(5)}$$

$$\sigma_{tS} = E \cdot \frac{m^2}{m^2 - 1}\left\{\varepsilon_{tS} + \frac{\varepsilon_{aS}}{m}\right\} \quad \text{.....(6)}$$

and for the three-dimensional case, from equations (3) and (4) :

$$\sigma_{aK} = E \cdot \frac{(m-1)\, e_{aK} + 2 e_{rK}}{m - 1 - \frac{2}{m}} \quad \ldots\ldots\ldots(7)$$

$$\sigma_{rK} = E \cdot \frac{e_{aK} + m e_{rK}}{m - 1 - \frac{2}{m}} \quad \ldots\ldots\ldots(8)$$

But the indicated strains at the surface (equations (5) and (6)) cannot be measured directly. They are obtained if the strains e_{aL} which occur on cutting away a layer from the bar are multiplied by the ratio of the cross-sections of the remnant parts to the cross-sections of the removed parts of the body. Instead of using the inner radius of the removed layer, its mean radius r_m can be used, if the thickness Δr of the layer is taken very small in comparison with the radius r.

Thus:

$$\frac{e_{aS}}{-e_{aL}} = \frac{\pi r_m^{\,2}}{2\pi r_m \Delta r}.$$

If the infinitesimal change of length $d\Delta l$ results from removing a surface layer of thickness $d\Delta r$, this equation becomes, since $e_{aL} = \frac{d\Delta l}{l}$:

$$e_{aS} = -\frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots\ldots(9)$$

Introducing the notations:

$$\delta_S = e_{tS}/e_{aS} \quad \ldots\ldots\ldots(10)$$

$$\delta_K = e_{rK}/e_{aK} \quad \ldots\ldots\ldots(11)$$

for the ratio of the surface strains and the core strains, respectively, resulting from uni- or multi-axial stresses, and using equations (9)–(11) in equations (5)–(8), the equations:

$$\sigma_{aS} = -E \cdot \frac{m^2}{m^2-1} \cdot \frac{m+\delta_S}{m} \cdot \frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots(12)$$

$$\sigma_{tS} = -E \cdot \frac{m^2}{m^2-1} \cdot \frac{m\delta_S + 1}{m} \cdot \frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots(13)$$

for the surface, and:

$$\sigma_{aK} = E \cdot \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}} \cdot e_{aK} \quad \ldots\ldots\ldots(14)$$

$$\sigma_{rK} = E \cdot \frac{1 + m\delta_K}{m - 1 - \frac{2}{m}} \cdot e_{aK} \quad \ldots\ldots\ldots(15)$$

for the core, are obtained.

Equations (12)–(15) represent the stresses obtained from the measured strains after the removal of a single layer. The strain e_{aK} can be determined only after the removal of so many layers that the body is stress-relieved. The difference between the final length change Δl_o and the length change $\Sigma\Delta l$ after the removal of a sum of layers with the individual changes Δl_1, Δl_2, Δl_3, ..., is $l.e_{aK}$; that is:

$$l.e_{aK} = \Delta l_o - \Sigma\Delta l,$$

and consequently:

$$\Sigma\Delta l = \Delta l_o - l.e_{aK} \quad \ldots\ldots\ldots(16)$$

To obtain the amount by which the stresses of the core are relieved by removing outside layers, the values e_{aK} in equations (14) and (15) have to be replaced by $\Sigma\Delta l/l$. These modified equations (14) and (15) must be subtracted from equations (12) and (13), respectively, to obtain the axial and tangential residual stresses σ_{aR} and σ_{tR}. This follows from the fact that the dimensions of the whole specimen are considerably altered during the removal of a large number of layers. The layers under the removed layers are therefore in an altered state of stress when they are themselves removed. This fact must be considered after each removal, to determine the original state of stress which existed before the first part was cut away. Heyn[7] considered this and developed an equation for the calculation of the residual stress σ_{aR} in the axial direction, assuming that all the stresses are effective in this direction and that Poisson's ratio could be made zero. According to Sachs,[24] the latest version of this equation, using the present notation, is:

$$\sigma_{aR} = -\frac{E}{l}\left\{\frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \Sigma\Delta l\right\} \quad \ldots\ldots\ldots(17)$$

The form of this equation for multiaxial stress, corresponding to equations (12)–(15), can now be obtained by superposition, since the measured surface stresses can be assumed to be bi-axial, and the sum of the stresses, relieved by the removal of the layers above the calculated layer, can be assumed to be tri-axial. The final residual stresses can therefore be written:

$$\sigma_{aR} = -\frac{E}{l}\left\{\frac{m^2}{m^2-1} \cdot \frac{m+\delta_S}{m} \cdot \frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}} \cdot \Sigma\Delta l\right\} \ldots(18)$$

in the axial direction, and:

$$\sigma_{tR} = -\frac{E}{l}\left\{\frac{m^2}{m^2-1} \cdot \frac{m\delta_S + 1}{m} \cdot \frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \frac{1 + m\delta_K}{m - 1 - \frac{2}{m}} \cdot \Sigma\Delta l\right\} \ldots(19)$$

in the tangential direction.

Equation (18) differs from Heyn's formula only by the factors:

$$\frac{m^2}{m^2-1} \cdot \frac{m+\delta_S}{m} \quad \text{and} \quad \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}}.$$

These factors become equal to 1 if it is assumed that Poisson's ratio $\nu = 1/m = 0$, and that $\delta_S = 0$ or $\delta_K = 0$, respectively.

Equation (19) arises because of the relationship of the strains in the principal axes. The radial stresses are equal to the tangential stresses in the interior of the body, but become zero on reaching the surface, where the tri-axial state of stress has changed to a bi-axial one.

The axial stresses in Fig. 7*a* were calculated from the strain measurements in Fig. 6, using equation (18). In the core, the stresses are much greater in the axial direction than in the radial direction. The lateral contractions caused by the axial stresses are therefore greater than the strains resulting from the radial stresses. The bar therefore contracts in diameter, in spite of the fact that tension stresses are effective in the radial direction, *i.e.*, the radial or the tangential strains are negative. The strain ratio of the core $\delta_K = e_{tK}/e_{aK} < 0$. The compression of the surface

in the axial and in the tangential direction is barely influenced by this, as the accumulated elastic strains are from ten to twenty times the strains of the core. The surface strain ratio $\delta_S = e_{tS}/e_{aS} > 0$, and it is therefore necessary to use two strain ratios, a negative one for the core and a positive one for the surface. The tangential stress was calculated on the assumption that the strain ratios remain constant, the values being δ_K in the core and δ_S in the surface. Thus the calculation of the tangential stresses is essentially simplified. The assumption that the strain ratios δ_K and δ_S are constant is certainly not entirely correct, but it is the best assumption to make, since the tangential strains have not been measured. The inaccuracy introduced by assuming constant strain ratios, and by the estimation of their size, does not exceed other inaccuracies in the determination of the stresses. An error of about $\pm$ 30% in the estimation of the strain ratios affects the calculation of the axial stresses to about $\pm$ 10% in the most unfavourable case. Therefore, comparatively severe simplifying assumptions as to the value of the strain ratio can nevertheless enable fairly accurate stress calculations to be made. Even the most inaccurate estimation of the strain ratios is much better than the assumption that Poisson's ratio is equal to zero.

The axial and tangential stresses in Fig. 7*a* were calculated assuming that for section *a–b* of the curve the radial stress $\sigma_{rS} = 0$, and that for section *b–d* the radial stress is equal to the tangential stress, *i.e.*, $\sigma_{rS} = \sigma_{tS}$. The strain ratio for section b–c_1 is :

$$\delta_S = e_{rS}/e_{aS} = e_{tS}/e_{aS} = +\,0{\cdot}15.$$

For the further course of the stresses, from c_2 to d, it must be considered that the stresses in the axial direction are far greater than in the tangential (= radial) direction. Because of the lateral contraction, $e_{tK} = e_{rK}$ has a negative value. The strain ratio for the core was found, from the conditions of equilibrium of the stresses in the longitudinal section and over the cross-section, to be :

$$\delta_K = e_{rK}/e_{aK} = e_{tK}/e_{aK} = -\,0{\cdot}08.$$

The conditions of equilibrium are represented by the integrals of the stresses for the longitudinal section and cross-section, which must become zero if the tension stresses of the core are in balance with the compression stresses of the surface. Therefore :

$$\int_0^{r^2} \sigma_{aR}\, d(r^2) = 0 \text{ and } \int_0^{r} \sigma_{tR}\, d(r) = 0 \qquad \text{.....(20)}$$

where σ_{aR} and σ_{tR} represent the axial and tangential residual stresses, respectively, and r is the radius of the cylinder. The conditions of equilibrium are always fulfilled. The assumed strain ratios are altered so that both integrals in equations (20) are satisfied. This is justified as equations (20) are exact, whereas the assumption of constant strain ratios is not completely accurate. The conditions of equilibrium of equations (20) are sufficient to obtain a well-defined stress distribution over the cross-section of the specimen, after correcting the assumed values of the strain ratios. The alteration of the strain ratios from the core to the surface layer takes place rather suddenly between c_1 and c_2 (Fig. 7), which is one reason for the suitability of this method.

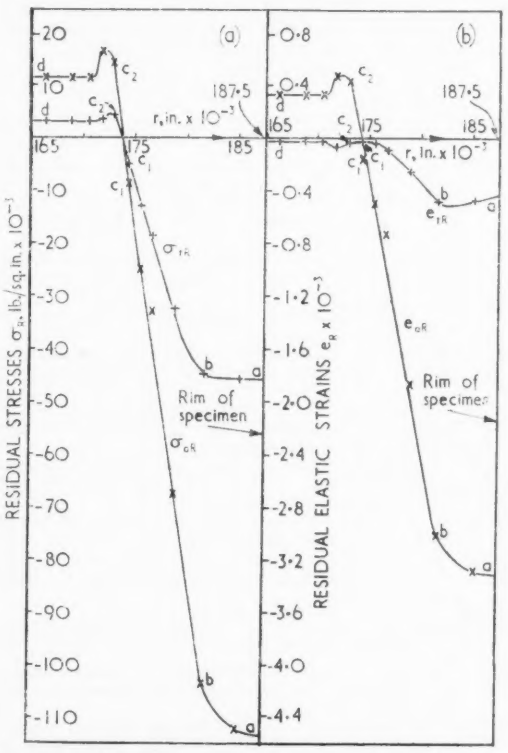

Fig. 7—Residual stresses and elastic strains in shot-peened bar used for Fig. 6. (*a*) Residual stresses ; (*b*) elastic strains

In Figs. 8*a* and *b*, the areas I and II, which are situated between the curves $\sigma_{aR} = f(r^2)$ and $\sigma_{tR} = f(r)$ and the zero line, must be equal in size in the respective figures. In this case the conditions of equilibrium according to equations (20) are fulfilled. In Sachs' formulæ, only the first equation of equilibrium is fulfilled, and therefore the tangential and radial stresses cannot be calculated accurately from these formulæ. In the Sachs' equations, as mentioned previously, the strains produced by the stresses in the third axis (radial stresses) are not considered. In the opinion of the present author, both these reasons justify the determination of the residual stresses in the specimens by removing cylindrical layers from the outside, instead of boring them out. The removal of outside layers is the only method which allows a mechanical determination of stresses in specimens of small diameter, especially when the stresses are limited to thin surface layers, as is the case in shot-peened or surface-rolled cylindrical bars with a diameter less than 2 in. It should be emphasized, however, that in principle it is better to measure both the change in length and the change in diameter, as is done in the boring-out method. However, the unavoidable inaccuracies introduced by the Sachs' formulæ in the calculation of the stresses are greater than the inaccuracies of the more primitive method of removing layers from the surface with only one measurable principal strain. Future research will

$$\sigma_{aK} = E \cdot \frac{(m-1)\,e_{aK} + 2e_{rK}}{m - 1 - \frac{2}{m}} \quad \ldots\ldots\ldots(7)$$

$$\sigma_{rK} = E \cdot \frac{e_{aK} + m e_{rK}}{m - 1 - \frac{2}{m}} \quad \ldots\ldots\ldots(8)$$

But the indicated strains at the surface (equations (5) and (6)) cannot be measured directly. They are obtained if the strains e_{aL} which occur on cutting away a layer from the bar are multiplied by the ratio of the cross-sections of the remnant parts to the cross-sections of the removed parts of the body. Instead of using the inner radius of the removed layer, its mean radius r_m can be used, if the thickness Δr of the layer is taken very small in comparison with the radius r.

Thus:

$$\frac{e_{aS}}{-e_{aL}} = \frac{\pi r_m^2}{2\pi r_m \Delta r}.$$

If the infinitesimal change of length $d\Delta l$ results from removing a surface layer of thickness $d\Delta r$, this equation becomes, since $e_{aL} = \frac{d\Delta l}{l}$:

$$e_{aS} = -\frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots\ldots(9)$$

Introducing the notations:

$$\delta_S = e_{tS}/e_{aS} \quad \ldots\ldots\ldots(10)$$

$$\delta_K = e_{rK}/e_{aK} \quad \ldots\ldots\ldots(11)$$

for the ratio of the surface strains and the core strains, respectively, resulting from uni- or multi-axial stresses, and using equations (9)–(11) in equations (5)–(8), the equations:

$$\sigma_{aS} = -E \cdot \frac{m^2}{m^2-1} \cdot \frac{m + \delta_S}{m} \cdot \frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots(12)$$

$$\sigma_{tS} = -E \cdot \frac{m^2}{m^2-1} \cdot \frac{m\delta_S + 1}{m} \cdot \frac{r_m}{2l} \cdot \frac{d\Delta l}{d\Delta r} \quad \ldots\ldots(13)$$

for the surface, and:

$$\sigma_{aK} = E \cdot \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}} \cdot e_{aK} \quad \ldots\ldots\ldots(14)$$

$$\sigma_{rK} = E \cdot \frac{1 + m\delta_K}{m - 1 - \frac{2}{m}} \cdot e_{aK} \quad \ldots\ldots\ldots(15)$$

for the core, are obtained.

Equations (12)–(15) represent the stresses obtained from the measured strains after the removal of a single layer. The strain e_{aK} can be determined only after the removal of so many layers that the body is stress-relieved. The difference between the final length change Δl_o and the length change $\Sigma\Delta l$ after the removal of a sum of layers with the individual changes Δl_1, Δl_2, Δl_3, ..., is $l.e_{aK}$; that is:

$$l.e_{aK} = \Delta l_o - \Sigma\Delta l,$$

and consequently:

$$\Sigma\Delta l = \Delta l_o - l.e_{aK} \quad \ldots\ldots\ldots(16)$$

To obtain the amount by which the stresses of the core are relieved by removing outside layers, the values e_{aK} in equations (14) and (15) have to be replaced by $\Sigma\Delta l/l$. These modified equations (14) and (15) must be subtracted from equations (12) and (13), respectively, to obtain the axial and tangential residual stresses σ_{aR} and σ_{tR}. This follows from the fact that the dimensions of the whole specimen are considerably altered during the removal of a large number of layers. The layers under the removed layers are therefore in an altered state of stress when they are themselves removed. This fact must be considered after each removal, to determine the original state of stress which existed before the first part was cut away. Heyn[7] considered this and developed an equation for the calculation of the residual stress σ_{aR} in the axial direction, assuming that all the stresses are effective in this direction and that Poisson's ratio could be made zero. According to Sachs,[21] the latest version of this equation, using the present notation, is:

$$\sigma_{aR} = -\frac{E}{l}\left\{\frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \Sigma\Delta l\right\} \quad \ldots\ldots\ldots(17)$$

The form of this equation for multiaxial stress, corresponding to equations (12)–(15), can now be obtained by superposition, since the measured surface stresses can be assumed to be bi-axial, and the sum of the stresses, relieved by the removal of the layers above the calculated layer, can be assumed to be tri-axial. The final residual stresses can therefore be written:

$$\sigma_{aR} = -\frac{E}{l}\left\{\frac{m^2}{m^2-1} \cdot \frac{m + \delta_S}{m} \cdot \frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}} \cdot \Sigma\Delta l\right\} \ldots(18)$$

in the axial direction, and:

$$\sigma_{tR} = -\frac{E}{l}\left\{\frac{m^2}{m^2-1} \cdot \frac{m\delta_S + 1}{m} \cdot \frac{r_m}{2} \cdot \frac{d\Delta l}{d\Delta r} - \frac{1 + m\delta_K}{m - 1 - \frac{2}{m}} \cdot \Sigma\Delta l\right\} \ldots(19)$$

in the tangential direction.

Equation (18) differs from Heyn's formula only by the factors:

$$\frac{m^2}{m^2-1} \cdot \frac{m + \delta_S}{m} \quad \text{and} \quad \frac{m - 1 + 2\delta_K}{m - 1 - \frac{2}{m}}.$$

These factors become equal to 1 if it is assumed that Poisson's ratio $\nu = 1/m = 0$, and that $\delta_S = 0$ or $\delta_K = 0$, respectively.

Equation (19) arises because of the relationship of the strains in the principal axes. The radial stresses are equal to the tangential stresses in the interior of the body, but become zero on reaching the surface, where the tri-axial state of stress has changed to a bi-axial one.

The axial stresses in Fig. 7*a* were calculated from the strain measurements in Fig. 6, using equation (18). In the core, the stresses are much greater in the axial direction than in the radial direction. The lateral contractions caused by the axial stresses are therefore greater than the strains resulting from the radial stresses. The bar therefore contracts in diameter, in spite of the fact that tension stresses are effective in the radial direction, *i.e.*, the radial or the tangential strains are negative. The strain ratio of the core $\delta_K = e_{tK}/e_{aK} < 0$. The compression of the surface

in the axial and in the tangential direction is barely influenced by this, as the accumulated elastic strains are from ten to twenty times the strains of the core. The surface strain ratio $\delta_S = e_{tS}/e_{aS} > 0$, and it is therefore necessary to use two strain ratios, a negative one for the core and a positive one for the surface. The tangential stress was calculated on the assumption that the strain ratios remain constant, the values being δ_K in the core and δ_S in the surface. Thus the calculation of the tangential stresses is essentially simplified. The assumption that the strain ratios δ_K and δ_S are constant is certainly not entirely correct, but it is the best assumption to make, since the tangential strains have not been measured. The inaccuracy introduced by assuming constant strain ratios, and by the estimation of their size, does not exceed other inaccuracies in the determination of the stresses. An error of about $\pm$ 30% in the estimation of the strain ratios affects the calculation of the axial stresses to about $\pm$ 10% in the most unfavourable case. Therefore, comparatively severe simplifying assumptions as to the value of the strain ratio can nevertheless enable fairly accurate stress calculations to be made. Even the most inaccurate estimation of the strain ratios is much better than the assumption that Poisson's ratio is equal to zero.

The axial and tangential stresses in Fig. 7*a* were calculated assuming that for section *a–b* of the curve the radial stress $\sigma_{rS} = 0$, and that for section *b–d* the radial stress is equal to the tangential stress, *i.e.*, $\sigma_{rS} = \sigma_{tS}$. The strain ratio for section b–c_1 is :

$$\delta_S = e_{rS}/e_{aS} = e_{tS}/e_{aS} = +0{\cdot}15.$$

For the further course of the stresses, from c_2 to d, it must be considered that the stresses in the axial direction are far greater than in the tangential (= radial) direction. Because of the lateral contraction, $e_{tK} = e_{rK}$ has a negative value. The strain ratio for the core was found, from the conditions of equilibrium of the stresses in the longitudinal section and over the cross-section, to be :

$$\delta_K = e_{rK}/e_{aK} = e_{tK}/e_{aK} = -0{\cdot}08.$$

The conditions of equilibrium are represented by the integrals of the stresses for the longitudinal section and cross-section, which must become zero if the tension stresses of the core are in balance with the compression stresses of the surface. Therefore :

$$\int_0^{r^2} \sigma_{aR}\, d(r^2) = 0 \text{ and } \int_0^{r} \sigma_{tR}\, d(r) = 0 \ldots\ldots\ldots (20)$$

where σ_{aR} and σ_{tR} represent the axial and tangential residual stresses, respectively, and r is the radius of the cylinder. The conditions of equilibrium are always fulfilled. The assumed strain ratios are altered so that both integrals in equations (20) are satisfied. This is justified as equations (20) are exact, whereas the assumption of constant strain ratios is not completely accurate. The conditions of equilibrium of equations (20) are sufficient to obtain a well-defined stress distribution over the cross-section of the specimen, after correcting the assumed values of the strain ratios. The alteration of the strain ratios from the core to the surface layer takes place rather suddenly between c_1 and c_2 (Fig. 7), which is one reason for the suitability of this method.

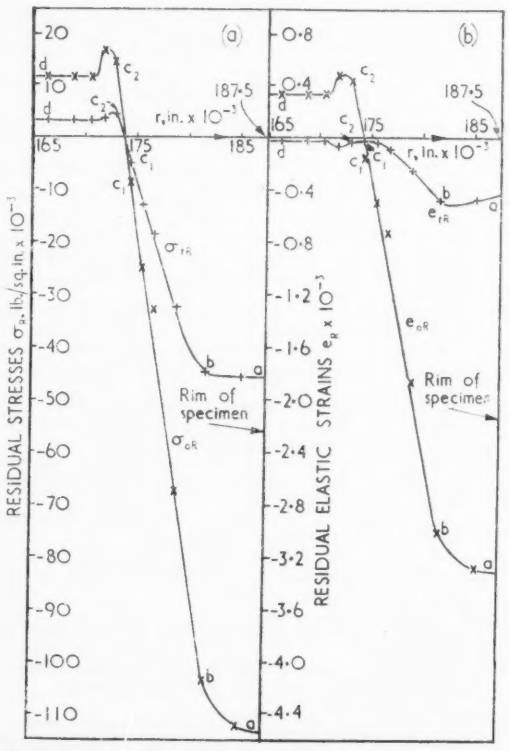

Fig. 7—Residual stresses and elastic strains in shot-peened bar used for Fig. 6. (*a*) Residual stresses ; (*b*) elastic strains

In Figs. 8*a* and *b*, the areas I and II, which are situated between the curves $\sigma_{aR} = f(r^2)$ and $\sigma_{tR} = f(r)$ and the zero line, must be equal in size in the respective figures. In this case the conditions of equilibrium according to equations (20) are fulfilled. In Sachs' formulæ, only the first equation of equilibrium is fulfilled, and therefore the tangential and radial stresses cannot be calculated accurately from these formulæ. In the Sachs' equations, as mentioned previously, the strains produced by the stresses in the third axis (radial stresses) are not considered. In the opinion of the present author, both these reasons justify the determination of the residual stresses in the specimens by removing cylindrical layers from the outside, instead of boring them out. The removal of outside layers is the only method which allows a mechanical determination of stresses in specimens of small diameter, especially when the stresses are limited to thin surface layers, as is the case in shot-peened or surface-rolled cylindrical bars with a diameter less than 2 in. It should be emphasized, however, that in principle it is better to measure both the change in length and the change in diameter, as is done in the boring-out method. However, the unavoidable inaccuracies introduced by the Sachs' formulæ in the calculation of the stresses are greater than the inaccuracies of the more primitive method of removing layers from the surface with only one measurable principal strain. Future research will

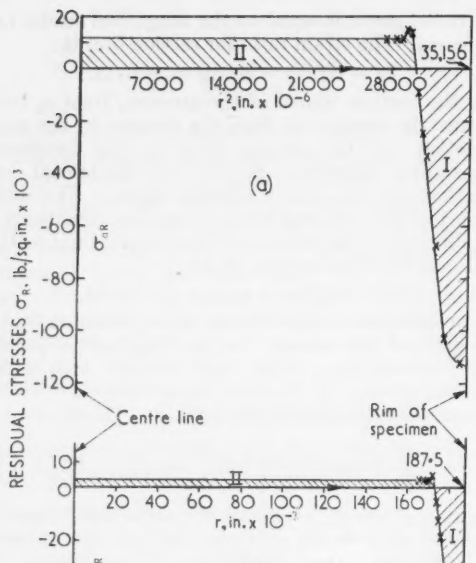

Fig. 8—The residual stresses of Fig. 7*a*, showing equality of shaded areas. (*a*) Axial direction ; (*b*) tangential direction

show if it is preferable to replace the Sachs' formulæ by a more complicated calculation which considers that the tri-axial state of stress passes gradually to a bi-axial state of stress during the boring-out, or if the stresses in the core can be measured directly by other experimental techniques.

From the stresses in Fig. 7*a*, the strains e_{aR} and e_{tR} in Fig. 7*b* were calculated, using equations (3) and (4) for the tri-axial state of stress. At the surface, $\sigma_{rR} = 0$, whilst near the surface σ_{rR} has a small value. The tri-axial state of stress in a thin surface layer can therefore be replaced by a bi-axial state of stress. The curve in Fig. 7*b* from *a* to *b*, *i.e.*, the two points near to the surface, was plotted from calculations from equations (1) and (2).

From Fig. 7*b* it can be seen that in the tangential direction at a point at a depth of about 0·013 in., $e_{tR} = 0$. At this point the axial strain changes from a positive to a negative value. One is inclined to assume that the calculation of these points is considerably influenced by the change of the strain ratio at the surface to the strain ratio of the core. This, however, is not the case. Between the two points c_1 and c_2 it was simply assumed that the positive strain ratio of the surface changed suddenly and was replaced by the strain ratio of the core.

STRESS REVERSAL IN PLANE SHEETS

The stress reversal found by numerous authors, as previously mentioned, was not observed in plane residually stressed bodies. Stress calculations have, however, been made on shot-peened plane surfaces.[22, 23] The camber produced on such surfaces, when the shot-peening was carried out on only one side of the sheet, was measured with an Almen gauge.[24] The camber was found to have its maximum value after the shot-peening. If the plastically deformed layer is removed, the camber becomes smaller and finally disappears.

Acknowledgments

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APPENDIX

Etching of Plastically Deformed Layers from Cylindrical Bars and the Measurement of Resultant Length Changes

A layer of thickness Δr is removed from the plastically deformed surface of a residually stressed cylindrical bar by each etching step. The residual stresses present because of the surface layer, disappear when the layer is dissolved, while the length change Δl occurs in the rest of the bar. The etching is continued until all residual stresses have disappeared. The values of the length changes Δl and the corresponding thicknesses Δr of the layers removed must be measured as accurately as possible. The accuracy of calculation of the residual stresses, according to equations (18) and (19), depends mainly upon these measurements.

Before etching, the end 0·2 in. of each test bar is dipped in a hot paraffin bath, to protect it from the attack of the acid. The other parts of the surface are left unprotected. Dilute nitric acid is suitable for the etching, as it gives a strong and uniform attack. The specimens become covered with iron oxide, which produces a mat black surface that prevents corrosion after the specimens have been washed.

The specimens are placed vertically in the acid bath and are cleaned continually from any adhering deposition. About ten minutes are needed to remove 2–5 g. from specimens of the size used, when dilute HNO_3 of specific gravity 1·10–1·15 g./c.c. is used. The speed of dissolution depends on the temperature and strength of the acid.

On removal from the bath the specimens are washed and dried. The paraffin wax protecting the ends can easily be cut away with a knife. Measurements are made, and the etching is then continued in the same way until no further length changes can be detected.

The thickness Δr of the layer etched away can only be determined roughly from the difference of the diameters before and after etching. It can, however, be calculated more accurately from the decrease in weight. In this case, only rough measurements of the diameters before and after etching are needed, from which the mean diameter of the layer etched away is determined. The layer etched away has the shape of a hollow cylinder, of which the thickness Δr can at once be calculated (if the mean diameter d_m, the length l, the weight ΔG, and the specific gravity γ of the material are known) from the equation :

$$\Delta r = \frac{\Delta G}{\gamma . d_m . \pi . l} .$$

The difference between the length l_K of a standard bar and the length l_P of the test bar is determined in a special measuring apparatus (Fig. 9). However, only the change of this difference, *i.e.*, the length change Δl, is needed to calculate the stresses. The standard bar represents a fixed length on the basis of which the test bar is compared. The same standard specimen is therefore used for all measurements made on the same test bar.

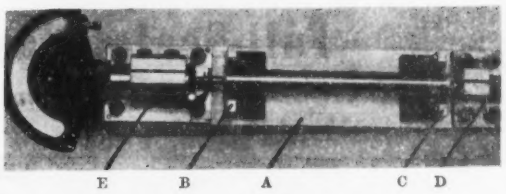

Fig. 9—The measuring apparatus

The measuring apparatus consists of a massive iron bed A on which are mounted two supports (B and C) for the test bar and into which are screwed two measuring jacks (D and E). A feeler is fixed in the measuring jack D, and in E is fixed a dial gauge having a scale divided in 0·001 mm. This means that length changes of 1 micron can be measured accurately, and changes of 0·1 micron can be estimated.

The measuring apparatus, the standard bar, and the test bars are kept in a thermostatically controlled room, to avoid changes in length of the bars owing to temperature differences. They must be kept there for about a day before the measurements can be made. The absolute value of the temperature of the room is unimportant, but it is only allowed to vary $\pm$ 1° C. in 12 hours, to ensure that the apparatus, the standard, and the test bars are at the same temperature to within $\pm$ 0·05° C. ($\pm$ 0·1 micron).

To make a measurement, the control bar is put into the apparatus and is rotated slowly on the support jacks, while observing the dial gauge. Over a full revolution, the value read on the dial gauge varies between a minimum of about — 10 microns and a maximum of about + 10 microns. Both values are read, which usually necessitates several rotations. The rotation of the specimen must always be carried out in the same sense.

The scale of the dial gauge is then adjusted to zero (either by moving the outer rim of the glass, or the scale itself) so that the maximum and the minimum values are equally spaced on either side of the zero point. This adjustment must be carried out only for the standard bar, so that all further specimens are compared at the same adjustment of the scale of the dial gauge.

After cleaning their ends, the test bars are placed carefully into the measuring apparatus. Maximum and minimum values are then read, and the average value is determined. These measurements are repeated several times. The final mean value of the different measurements gives the length difference between the test specimen and the standard bar, with an accuracy of about $\pm$ 0·1 micron. In this way the length changes caused by etching are determined. The difference between the values measured before and after etching is the length change Δl of the specimen that corresponds to the thickness Δr of the layer removed.

Full-Scale Blast-Furnace Trials

By J. A. Bond and T. Sanderson

SYNOPSIS

A study has been made of full-scale trials carried out at the Appleby-Frodingham and Workington branches of The United Steel Companies, Ltd. Details are given of selected trials, showing the benefits to be derived from better selection and preparation of raw materials, ore, and coke, and from the use of increased amounts of sinter in the burden. Brief reference is made to attempts to improve the distribution of the burden by alteration of design and to accelerate reduction by means of steam injection, thereby promoting smoother blast-furnace operation and increased output at a lower coke consumption. The main object of the paper, however, has been to demonstrate that full-scale trials are practicable in a large organization without undue disruption of the normal routine and output of the plant. It is emphasized that such trials require careful planning and subsequent statistical interpretation.

Introduction

LABORATORY work has provided much valuable data for the solution of blast-furnace problems, but the complex nature of the process demands that laboratory data should be checked by full-scale trials. The investigation of many aspects of ironmaking on a large scale, however, is dependent on the plant and materials readily available. Nevertheless, during the last few years numerous full-scale experiments have been carried out at the Appleby-Frodingham and Workington blast-furnace departments of The United Steel Companies, Ltd.

Brief details of some of the more interesting of the trials are given in the following pages. It should be emphasized that there has been no attempt to discuss fully the results obtained. In fact, the results, in themselves, are unimportant for the purpose of this paper, which is to show that full-scale trials are practicable, and to indicate the general procedure for carrying out such trials in a large organization.

Periodic reference will be made in the paper to such statistical matters as confidence limits and significance. The importance of this approach to the problem of large-scale trials has now been accepted for so long that there is perhaps a danger of passing over it without comment. It should, therefore, be pointed out that all such problems require careful planning and subsequent interpretation in the light of statistics; in this connection the authors wish to make special reference to the assistance received from the works statisticians in analysing the data collected during the trials at Appleby-Frodingham, much of which have been incorporated in this paper. Readers who intend to carry out similar trials themselves are recommended to consider a general article on statistics in heavy industry, by Swan,* and a more recent paper on blast-furnaces, by Sanderson and Wattleworth,† in which statistics are applied to the study of coke consumption. As a result of this latter work it was possible to build up a coke quality index and a further index for blast-furnace performance in which corrections are supplied for such properties as silicon in the iron, slag volume, and coke quality.

All the work has been done to solve problems peculiar to the Company concerned. No apology, however, is made for this, as full-scale trials must be carried out to solve the problems of a particular plant using particular raw materials.

The trials have been sub-divided into two sections:

Section I—Seven Trials carried out at Appleby-Frodingham (Lean-ore practice using a self-fluxing burden of Frodingham and Northants ores):

(1) The Effect of Selected Cokes and Graded Burdens
(2) The Effect of Screened and Dried Burdens
(3) The Effect of Welsh Coke
(4) The Effect of Blending Welsh Coal in the Coal Blend
(5) Bulk Interchange of Brookhouse and Thurcroft Slacks for Coking at the Respective Batteries
(6) The Influence of a Skirted Bell on Burden Distribution
(7) The Use of Steam in the Blast.

Section II—Four Trials carried out at Workington (Rich-ore practice using 80% Foreign ores and 20% Cumberland ores):

(1) The Effect on Coke Quality of the introduction of a Low Volatile Coal into the Blend
(2) The Effect of Blending Finely Ground Breeze in the Coal Blend
(3) The Effect of a High Percentage of Sinter in the Charge
(4) An Assessment of the Maximum Coke-Burning Rate of a Furnace.

Section I—APPLEBY-FRODINGHAM BLAST-FURNACE TRIALS

(1) THE EFFECT OF SELECTED COKES AND GRADED BURDENS

Earlier tests have been carried out using different methods of charging, with the object of distributing the various sizes of materials to the best advantage, *i.e.*, to obtain a distribution which would give the most efficient gas/solid contact, together with rapid driving. It was considered, as a result of these tests, that a simple redistribution of the smaller sizes did not necessarily increase the permeability of the stock column as a whole, but merely transferred the impermeable zone caused by segregation of the ore

* A. W. Swan, *Journal of The Iron and Steel Institute*, 1948, vol. 160, pp. 1–20.

† T. Sanderson and D. R. Wattleworth, *Journal of the Institute of Fuel*, 1950, vol. 23, No. 131, pp. 115–120.

Manuscript received 25th January, 1951.

Mr. Bond is Blast-Furnace Manager at the Appleby-Frodingham Steel Company, and Mr. Sanderson is Technical Assistant to the General Works Manager at the Workington Iron and Steel Company.

Table I

BURDEN/COKE COMBINATIONS USED IN TESTS

No.	Week Ending	No. 9 Furnace		No. 10 Furnace	
		Coke	Burden	Coke	Burden
1	26/4/47	Normal	Normal	Normal	Normal
2	10/5/47	Appleby-Frodingham	Good	Purchased	Poor
3	24/5/47	Purchased S. Yorks.	Good	Appleby-Frodingham	Poor
4	31/5/47		Poor		Good
5	7/6/47	Normal	Poor	Normal	Good
6	14/6/47	Normal	Normal	Normal	Normal

fines. Thus, little or no improvement in driving speed or fuel economy was achieved, and elimination of the ore fines was therefore considered desirable.

Aim of Experiment

To determine the effect of the total elimination of fine material (defined for the purpose as material smaller than $\frac{5}{8}$ in.) on blast-furnace performance.

Experimental Procedure

The experiment covered a period of six weeks, and was carried out at Nos. 9 and 10 furnaces (22-ft. dia. hearths). For details of the Appleby-Frodingham blast-furnace plant, the reader is referred to The Iron and Steel Institute Special Report No. 30.* Different combinations of burdens and cokes were used at the two furnaces over the test period, and are given in Table I. The terms used in Table I are defined briefly as follows :

Burdens :

Good burden consisted of Frodingham ore screened over a $\frac{3}{8}$-in. screen, bedded, and rescreened (after reclaiming) over a $\frac{3}{4}$ in. × 2 in. screen ; Northants ore dried and screened over a $\frac{5}{8}$ in. × 2 in. screen ; and sinter handled with unusual care to prevent breakage.

Normal burden consisted of + $\frac{3}{8}$-in. Frodingham ore bedded but not rescreened ; dried Northants ore screened over a $\frac{3}{8}$-in. screen ; and sinter handled by grab in the normal manner.

Poor burden consisted of + $\frac{1}{2}$-in. Frodingham ore bedded but not rescreened ; undried Northants ore screened over a $\frac{5}{8}$-in. screen ; and sinter.

Coke :

Normal coke was a mixture of 60% of Appleby-Frodingham and 40% of purchased South Yorkshire cokes

Purchased coke was approximately 100% of South Yorkshire cokes

Appleby-Frodingham coke was approximately 90% of Appleby-Frodingham coke and 10% of purchased South Yorkshire cokes.

All the ordinary details of practice, such as blast temperature and charging sequence, were normal, and were not changed during the test period.

Results

The results obtained (combined with data given in Table I) are shown in Table II.

The maximum weekly output achieved by either of the two furnaces prior to the trials was 3700 tons.

A Table from a statistical report, comparing the iron tonnages produced for different burdens and cokes, is reproduced in Table III.

Conclusions

The results of the trials proved that the elimination of fines from the burden, combined with the use of the best coke available on the plant, improved the output of iron and decreased coke consumption. It was also evident from the smoother operation and increased blast volume that the permeability of the stock column was materially improved.

(2) THE EFFECT OF SCREENED AND DRIED BURDENS

The value of eliminating fines and partially dried ores had already been demonstrated, and it was considered that even greater benefits would be derived from an all-dried burden. Both the Frodingham and

* G. D. Elliot, " Ironmaking at Appleby-Frodingham." *The Iron and Steel Institute*, 1944, *Special Report No.* 30.

Table II

RESULTS OF TRIALS

Week Ending	No. 9 Furnace				No. 10 Furnace			
	Burden	Iron Output, tons	Coke	Coke Consumption, cwt./ton	Burden	Iron Output, tons	Coke	Coke-Burning Rate, cwt./ton
26/4/47	Normal	3260	Normal	23·25	Normal	3000	Normal	22·84
10/5/47	Good	4190	Appleby-Frodingham	22·33	Poor	2640	Purchased	23·52
24/5/47	Good	3220	Purchased	23·40	Poor	3460	Appleby-Frodingham	22·73
31/5/47	Poor	2460	Purchased	23·71	Good	4360	Appleby-Frodingham	22·40
7/6/47	Poor	3060	Normal	23·84	Good	3200	Normal	23·58
14/6/47	Normal	3140	Normal	23·54	Normal	3000	Normal	23·92

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Table III

STATISTICAL COMPARISON OF IRON OUTPUTS WITH VARIOUS FURNACE PRACTICES

Furnace Practices Compared		Increased Tonnage of Iron Output, tons/week	
		Best Estimate	Confidence Limits
Good burden	Normal or poor burden	710	550–870
Appleby-Frodingham coke	Normal	450	340–560
Normal	Purchased S. Yorks	450	340–560
Appleby-Frodingham coke	Purchased S. Yorks.	900	680–1120
Appleby-Frodingham coke, good burden	Normal	1160	990–1330
Normal	Purchased coke, poor burden	450	340–560
Appleby-Frodingham coke, good burden	Purchased coke, poor burden	1610	1380–1840

Northants ores, when crushed and screened in their 'as received' condition, have a high moisture content and a fairly low screening efficiency due to the quantity of fines which adhere to the rough stone and thus pass over the screens. A trial was therefore organized in which the fines were eliminated and the moisture contents reduced to comparatively low limits.

Aim of Experiment

To determine the effect of dried burdens on blast-furnace performance. Drying, for the purposes of the trial, was defined as a reduction in moisture from approximately 18% to 10% with Northants ore, and from approximately 12% to 6% with the Frodingham ore.

Experimental Procedure

The dried Frodingham ore consisted of the normal Frodingham ore (previously crushed, screened at $\frac{5}{8}$ in., bedded, and reclaimed) dried to 5–6% of moisture and then rescreened over a 2 in. × $\frac{3}{4}$ in. mesh screen.

The dried Northants ore used was the normal dried Northants 'rubble' screened over a $\frac{3}{8}$ in. screen.

The test was designed as follows :

No. 6 Furnace (17-*ft. dia. hearth*)

(i) Four weeks using normal burden
(ii) Two weeks transitional period, introducing dried Frodingham ore
(iii) Three weeks' use of dried Frodingham and Northants ore.

During the entire test period, a high percentage of coke I was used at this furnace.

No. 5 Furnace (17-*ft. dia. hearth*)

(i) Four weeks using normal burden
(ii) Two weeks using burden of dried Frodingham and Northampton ore.

During the entire test period, a high percentage of coke II was used at this furnace.

The following variables were examined :

(i) Number of charges
(ii) Iron output
(iii) Iron output corrected for all delays
(iv) Iron output corrected for Fe in burden and for all delays
(v) Coke consumption, cwt./ton of iron.

Table V

CONFIDENCE LIMITS OBTAINED FOR DIFFERENT VARIABLES, USING DRIED STONE

Variable	Lower Confidence Limit	Best Estimate	Upper Confidence Limit
No. of charges increase	60	134	208
Iron output increase (tons/week)	219	400	581
Iron output (corrected for delays)	333	480	627
Iron output (corrected for delays and for Fe in burden)	151	332	513
Decrease in coke consumption (cwt./ton of iron)			
No. 6 Furnace: coke I	2·35	0·62	−1·11
No. 5 Furnace: coke II	3·47	2·80	2·13

Table IV

COMPARISON OF NORMAL AND DRIED BURDENS

(Weekly Averages)

Type of Burden	Period, weeks	No. of Charges	Actual Iron Output, tons/week	Corrected* Iron Output, tons/week	Actual Coke Consumption, cwt./ton of iron	Fe in Burden, %
No. 5 Furnace						
Normal	4	615	1410	1441	28·84	29·04
Dried	2	745	1835	1870	26·04	31·50
No. 6 Furnace						
Normal	4	645	1605	1643	27·08	29·10
Dried	3	782	1980	1878	26·46	31·50

* Corrected for stoppage and Fe in burden

Results

The operation of the furnaces changed almost immediately on the introduction of the dried and screened burdens. The furnaces worked faster and with less slipping. Some scouring took place, which resulted in an increased tuyere loss and a little off-grade iron.

The details of the operation are shown in Table IV.

The value of using dried stone was calculated, and a test was made to see whether the results of the two furnaces differed significantly. The difference was significant only for the coke consumption. Confidence limits (1 in 20) were therefore calculated, and are shown in Table V.

Conclusions

The effects of the dried and screened burdens were to promote smoother furnace operation, to increase the output of iron, and to decrease coke consumption, although this was not statistically significant in No. 6 furnace.

(3) THE EFFECT OF WELSH COKE

Many full-scale trials have been carried out to show the great influence that coke quality has on blast-furnace performance, and the use of Welsh coke has been selected as an example. The problem of coke quality is especially important at Appleby-Frodingham, because :

(i) The ferruginous raw materials are of poor quality, the Frodingham ore being of very low grade

(ii) The slag volume necessarily associated with these low-grade ores is very high, averaging about 25 cwt./ton of iron

(iii) For geographical reasons, the obvious fuel is South Yorkshire coke, or coke made locally from South Yorkshire coals. These are generally accepted as being inferior to the coking coals of South Wales

(iv) Since 1940, the Frodingham ore, comprising 66% of the burden, has deteriorated in quality, particularly with regard to the iron and sulphur contents. The sulphur content of South Yorkshire coke, also, has risen.

Aim of the Experiment

To determine the value, to the practice, of using the best coke available. This was a Welsh coke, and three separate consignments were obtained for test runs on three different furnaces.

The particular aims of the test runs were :

(i) To assess the value of a high percentage of good coke

(ii) To assess the value of a small percentage of good coke

(iii) To confirm the results obtained in the first two tests.

Experimental Procedure

By using the Welsh coke on different furnaces in different departments in the ironworks, the effects of plant factors, such as management and furnace conditions, were minimized.

Test 1 was carried out at No. 5 furnace (17-ft. dia. hearth) ; 75% of Welsh coke was charged for 30 hours, and the charge was then reduced to 50% and maintained for 10 hours.

Test 2 was carried out at No. 4 furnace (17-ft. dia. hearth) ; 50% of Welsh coke was charged for 8 hours, and the charge was then reduced to 25% and maintained for 4 days.

Table VI
OPERATING DETAILS OF TESTS

Period	Charges	Checks	Slips	Iron Analysis		Weight of Ore per Charge, lb.	Blast Temperature, °C.	Iron Output, tons/day
				Si, %	S, %			
No. 4 Furnace								
Nine days before Welsh coke	102	10	5	1·02	0·063	17,700	530 (986° F.)	215
Four days of Welsh coke	118	6	6	1·01	0·073	18,500	480 (896° F.)	251
Nine days after Welsh coke	105	12	4	1·00	0·072	18,800	500 (932° F.)	230
No. 5 Furnace (Daily Record)								
23/1/50 (100% Yorks. coke)	95	14	6	1·16	0·064	16,250	580 (1076° F.)	204
24/1/50 (100% Yorks. coke)	96	12	8	1·18	0·118	16,000	630 (1160° F.)	227
25/1/50 (100% Yorks. coke)	99	18	4	1·31	0·066	16,000	560 (1040° F.)	245
26/1/50 (100% Yorks. coke)	86	18	2	0·87	0·100	16,000	570 (1058° F.)	216
27/1/50 (75% Welsh coke)	92	22	2	0·89	0·128	16,000	610 (1130° F.)	190
28/1/50 (50% Welsh coke)	118	4	5	1·31	0·063	16,250	480 (896° F.)	301
29/1/50 (100% Yorks. coke)	102	2	7	0·76	0·104	16,000	510 (950° F.)	237
30/1/50 (100% Yorks. coke)	97	16	7	1·00	0·084	15,750	580 (1076° F.)	232
31/1/50 (100% Yorks. coke)	98	13	4	1·25	0·128	15,750	590 (1094° F.)	234

Test 3 was carried out at No. 6 furnace (17-ft. dia. hearth) ; 66% of Welsh coke was charged for 4 hours, followed by 50% for 10 hours. The charge was then reduced to 28% and maintained for 9 days.

The duration of the trials was limited by the short supplies of Welsh coke. Ore burdens were normal, and all alterations of practice were those necessitated by the change in furnace condition following the charging of the better coke.

Results

It was observed in all the trials that :

(i) Within six hours of the coke entering the furnace, blast pressure for a given volume eased appreciably. This was undoubtedly due to the increased gas space in the furnace, arising from the better size grading and freedom from smalls of the Welsh coke.

(ii) A dirty cast was experienced in the first 24 hours, which suggested accelerated working of parts of the furnace that are normally very sluggish.

(iii) It was necessary to reduce blast temperature (from about 600° C. to 450° C.) until increased burden could be charged, to avoid making very high silicon iron.

(iv) The beneficial effects of using Welsh coke persisted for some time.

The principal operating figures concerned in the tests are given in Tables VI and VII.

The results are especially valuable in showing how the production of pig iron from domestic ores could be increased appreciably by the use of cokes of better quality than can be produced from the coal geographically nearest to the ore field.

A statistical examination of the results revealed that an addition of 10% of Welsh coke gave an increase of 104 tons per week per furnace (of 1600-ton weekly capacity). The increase is much larger (166 tons) if allowance is made for the benefits which continue for some time after the coke has been taken off.

Conclusions

The addition of 10% of Welsh coke promoted smoother furnace operation, permitted the use of lower blast temperatures, and substantially increased the output of iron. It is estimated that if Welsh coke could be used regularly as in the tests carried out, *i.e.*, two or three days at 30–50% followed by several days on South Yorkshire coke, the output of iron at Appleby-Frodingham could be increased by 1660 ± 520 tons on a 16,000-tons/wk. production.

(4) THE EFFECT OF BLENDING WELSH COAL IN THE COAL BLEND

The results of the furnace trials run with a proportion of Welsh coke in the burden showed that the use of 10% of Welsh coke raised the output rate of the furnaces by 6–10%. Unfortunately, Welsh coke was procurable only in small consignments and it was impossible to obtain a regular supply in quantities large enough to benefit the furnaces. However, supplies of suitable Welsh coals became available for a short time, and blending trials were commenced.

Aim of the Experiment

To determine the effect on coke quality and blast-furnace performance of a Welsh coal in the coal blend at Appleby-Frodingham.

Experimental Procedure

The Welsh coal was charged into the blending bunker at the coke ovens for seven days (starting on Thursday, 9th March, 1950), and made up 10% of the blend. This was expected to affect the coke for the seven days from 11th to 17th March, inclusive ; coke samples were therefore taken for each shift for the 21 days from 5th to 25th March. This gave seven days on either side of the ' Welsh Coal Test Week ' for comparison. The following variables were studied :

(i) + 4-in., + 3-in., + 2-in., + 1½-in., + ¾-in., sizing
(ii) + 2-in., + 1½-in., + 1-in., + ½-in., shatter
(iii) Cochrane and Haven Indices

} Physical properties of the coke

Table VII

OPERATING DETAILS OF TESTS

No. 6 Furnace (Daily Record)

Period		Charges	Checks	Slips	Load, lb.	Blast Pressure, lb./sq. in.	Blast Temperature, °C.	Iron Output, tons/day
29/6/50	100% Yorks. coke	111	19	8	18,500	11¼	560 (1040° F.)	267
30/6/50		118	19	5	18,000	11	560 (1040° F.)	287
1/7/50		113	16	4	18,500	11	475 (887° F.)	290
2/7/50		97	20	3	18,500	11	540 (1004° F.)	180
3/7/50	Addition of Welsh coke	114	21	4	18,750	11¼	450 (842° F.)	304
4/7/50		110	5	—	18,750	10¼	480 (896° F.)	308
5/7/50		117	7	3	17,750	10	550 (1022° F.)	302
6/7/50		121	5	5	18,250	9¾	520 (968° F.)	297
7/7/50		125	5	6	18,250	9¾	520	317
8/7/50		128	2	7	18,250	9¾	520	292
9/7/50		132	2	7	17,500	9½	570 (1058° F.)	311
10/7/50		100	2	4	17,500	9	580 (1076° F.)	232
11/7/50		127	4	5	18,000	9½	470 (878° F.)	291
12/7/50	100% Yorks. coke	115	10	8	18,000	9½	570 (1058° F.)	285
13/7/50		114	15	7	17,750	9½	560 (1040° F.)	247
14/7/50		113	11	3	17,750	9½	530 (986° F.)	283

Table VIII
AVERAGE VALUES OF THE COKE VARIABLES

Variable	Week 1	Week 2	Week 3	Estimated Effect of Welsh Coal, with Standard Errors of the Estimates
+ 4-in. Sizing, %	9·9	10·9*	12·8	...
+ 3-in. Sizing, %	32·3	35·0*	35·3	...
+ 2-in. Sizing, %	77·8	79·7†	78·2	1·70 ± 0·43
+ 1½-in. Sizing, %	97·0	97·6†	96·9	0·68 ± 0·11
+ ¾-in. Sizing, %	99·25	99·26*	99·17	...
+ 2-in. Shatter, %	72·3	75·2†	72·2	2·95 ± 0·67
+ 1½-in. Shatter, %	86·6	88·4†	86·1	2·11 ± 0·19
+ 1-in. Shatter, %	94·2	95·2†	93·8	1·27 ± 0·16
+ ½-in. Shatter, %	97·5	97·9†	97·4	0·50 ± 0·05
Cochrane hardness	79·9	79·2*	79·1	...
Haven stability	61·1	65·4*	61·9	3·83 ± 0·44
H_2O, %	0·68	0·62	0·86	...
Ash, %	11·1	10·7*	10·6	...
Volatile matter, %	0·91	0·95	0·91	...
Sulphur, %	1·36	1·35	1·37	...

* Significantly different, at the 5% level, from one of the other two weeks
† Significantly different, at the 5% level, from both the other two weeks

(iv) H_2O, %, Ash, %, Volatile matter, %, Sulphur, % } Chemical properties of the coke

(v) H_2O, %, Ash, %, Volatile matter, %, Sulphur, %, ½-in. Sizing, % } Properties of the coal blend

The coal figures (v) were obtained from daily records for the period 22nd February to 25th March.

For the three weeks from 5/3/50 to 25/3/50, 100% of Appleby-Frodingham coke was charged to No. 9 furnace, the coke in the second of these three weeks having Welsh coal in its blend. Thus the effect of the Welsh blended coke on furnace performance during the second week could be compared with the performance for the two adjacent weeks. The following furnace variables were studied :

(i) Iron output
(ii) No. of charges
(iii) Si and S in iron, %
(iv) Blast pressure and blast temperature
(v) Checks and slips
(vi) Slag basicity (CaO/SiO_2 ratio)

Results

The introduction of Welsh coal into the blend slightly improved the chemical and physical properties of the coke, as shown in Table VIII.

The statistical estimate of the effect of 10% of Welsh coal in the blend during the three weeks of furnace trials is shown in Table IX.

The improvement in coke quality had an immediate effect on the speed of driving and the ease of operation, and thereby increased the output of iron and reduced the coke consumption.

Conclusions

The introduction of 10% of Welsh coal into the

Table IX
AVERAGE VALUES OF THE BLAST-FURNACE VARIABLES

Variable	Week 1	Week 2	Week 3	Estimated Effect of Welsh Coal, with Standard Errors of the Estimates
Daily iron output, tons	448	474*	437	+ 31·6 ± 14·4
Coke consumption, cwt./ton	22·61	22·43	22·92	...
No. of charges	43·4	46·1*	42·7	+ 3·1 ± 1·4
Checks and slips	4·9	4·4	5·0	...
Si in iron, %	0·72	0·66*	0·82	− 0·12 ± 0·038
S in iron, %	0·079	0·083	0·089	...
Blast pressure, lb./sq. in.	15·7	15·8	15·9	...
Blast temperature, °C.	412 (774° F.)	446* (835° F.)	429 (804° F.)	+ 25 ± 1·2
CaO/SiO_2 ratio	1·27	1·30	1·25	...

* Significantly different, at the 5% level, from both the other two weeks

Table X

ANALYSES OF COKES USED DURING TEST

Coke	Moisture, %	Dried at 100° C.		
		Ash, %	Sulphur, %	Volatile Matter, %
Brookhouse normal	3·30	8·85	1·52	1·4
Brookhouse slack in Thurcroft ovens (*B*)	5·25	9·65	1·58	1·23
Thurcroft normal	3·05	11·20	1·21	1·9
Thurcroft slack in Brookhouse ovens (*A*)	1·70	11·20	1·31	0·67

blend significantly improved the physical properties of the coke, increased the daily make of iron on the particular furnace by 31·6 tons, and decreased the coke consumption by 0·34 cwt./ton.

(5) BULK INTERCHANGE OF BROOKHOUSE AND THURCROFT SLACKS FOR COKING AT THE RESPECTIVE BATTERIES

Thurcroft coke had always had a strikingly beneficial effect on Appleby-Frodingham blast-furnaces, in regard to both output and coke rate, and as the coals used in its manufacture were used in other much inferior Yorkshire cokes, it was decided that an answer was required to the question whether the merits of the Thurcroft coke arose from the quality of the slacks or from the type of oven used.

Aim of the Experiment

To determine the effects of oven width, carbonizing rates, and temperature, on coke quality.

Experimental Procedure

The method of test decided upon was to coke the Thurcroft slacks in ovens of different dimensions and with a longer carbonizing time. The nearby Brookhouse battery was chosen for the test, as it is representative of the modern high-temperature, narrow oven practice whereas the Thurcroft battery represented the wide oven, low-temperature practice, as is shown in the following figures :

Battery	Mean Oven Width, in.	Carbonizing Time, hr.	Carbonizing Temperature, °C.
Brookhouse	18	20	1280
Thurcroft	21	35	1050

During the period of test, *i.e.*, the 28 days from May 6th to June 2nd, 1946, an interchange of 10,000 tons of slacks between Brookhouse and Thurcroft was put into operation. The conditions of carbonizing did not differ materially from normal practice.

A comprehensive test programme was carried out at both Brookhouse and Thurcroft, and also at Appleby-Frodingham where all the coke was received.

Results

Effect on Coke Quality—The yields of total test coke obtained were comparable to the yield of the normal practice of the respective ovens.

The analyses of the normal and test cokes are shown in Table X.

Tables XI and XII show the average results of sizing and mechanical tests taken at the respective ovens and at Appleby-Frodingham during the period of test.

Behaviour of the Cokes in the Blast-Furnaces—Coke *A* was used in No. 1 furnace from May 8th to June 4th, and Coke *B* in Nos. 5 and 6 furnaces from May 10th to June 11th, 1946.

The operating details are shown in Table XIII.

Considerable amounts of other cokes, apart from those given in Table XIII, were used during the

Table XI

OVEN RESULTS

Type of Coke	Sizing, %					Shatter, %		
	+ 3 in.	3–2 in.	2–1½ in.	1½–1 in.	− 1 in.	+ 2 in.	+ 1½ in.	+ ½ in.
Coke *A*	49·8	30·2	10·6	4·1	5·3	73·2	88·7	98·7
Coke *B*	45·2	27·0	15·0	7·1	5·7	69·6	82·5	98·5

Table XII

APPLEBY-FRODINGHAM RESULTS

Type of Coke	Sizing in Wagons, %					Shatter, %			Drum Test	
	+ 4 in.	4–3 in.	3–2 in.	2–1½ in.	− 1½ in.	+ 2 in.	+ 1½ in.	+ ½ in.	Haven + 1 in.	Cochrane + ½ in.
Coke *A*	17·3	33·7	33·6	10·8	4·6	78·3	89·9	97·9	67·1	74·7
Normal Thurcroft (Average 1945)	...	...	...	...	...	...	89·3	97·8	65·0	75·7
Normal Brookhouse (Average 1945)	...	...	...	...	...	...	77·0	97·1	60·1	77·4
Coke *B*	22·8	26·0	28·2	15·0	8·0	68·2	82·2	97·6	62·6	80·5

Table XIII

OPERATING DETAILS OF TESTS

No. of Weeks	Corrected Iron Output, tons/week		Coke Consumption, cwt./ton	Flue Dust, cwt./ton	Checks and Slips (Weekly Average)	Coke, %						Average Shatter Index	Sinter, %
	Average	Standard Error				Thurcroft	Coke *B*	Brookhouse	Coke *A*	Orgreave	Durham		
No. 1 Furnace (17-ft. dia. hearth)													
3	1673	74	24·59	4·64	56	...	...	29	...	17	31	76	46
4	1618	31	24·88	3·04	83	...	...	32	...	37	...	73	34
5	1656	27	23·91	3·37	84	...	...	67	...	22	2	76	39
5	1694	84	23·67	5·13	61	...	...	4	57	30	...	83	32
9	1732	49	24·56	4·01	64	...	...	58	...	8	...	76	26
No. 5 Furnace (17-ft. dia. hearth)													
4	1662	61	27·63	2·57	19	10	...	...	...	32	...	74	34
9	1948	41	26·73	2·29	27	49	...	...	...	22	...	81	36
6	1955	50	26·06	3·04	6	25	2	...	...	27	...	78	50
4	1895	61	24·84	3·40	2	...	26	...	...	31	...	76	56
5	1798	55	25·79	3·15	24	2	...	...	...	41	...	76	46
No. 6 Furnace (17-ft. dia. hearth)													
5	1180	58	28·64	3·43	113	1	...	...	...	32	...	72	34
6	1408	53	28·58	4·84	146	...	...	...	...	21	30	76	30
6	1533	53	28·09	7·82	116	26	1	...	...	26	1	79	34
4	1302	64	27·76	8·12	141	...	39	...	...	16	1	78	33
5	1422	58	29·30	8·02	116	1	...	...	...	39	...	76	21

period of the tests. The separate effects have not been considered, but they were allowed for in the calculation of average shatter indices.

The use of coke *A* increased the output of No. 1 furnace by 70 tons/week, but this was not significant statistically.

The use of coke *B* coincided with a deterioration in the output of No. 6 furnace compared with the period when normal Thurcroft coke was used. A similar effect, not large enough to be significant, was observed at No. 5 furnace.

Conclusions

The fast rate of carbonization coupled with a high temperature and narrow oven did not affect the mechanical properties of coke produced from Thurcroft slacks ; *i.e.*, the use of Brookhouse ovens for coking Thurcroft slack maintained the high shatter and good sizing of normal Thurcroft coke.

A slow rate of carbonization, coupled with a low-temperature, wide oven upgraded the shatter index of coke produced from Brookhouse slack ; *i.e.*, the use of Thurcroft ovens for coking Brookhouse slack improved the shatter index of normal Brookhouse coke.

Although the physical properties of the various cokes were not impaired, their performances in the blast-furnace differed according to the coking practice ; under the conditions of these trials, the fast rate of carbonization, coupled with the high temperature and narrow oven, produced a coke which had an inferior blast-furnace performance.

(6) THE INFLUENCE OF A SKIRTED BELL ON BURDEN DISTRIBUTION

The blast-furnaces at Appleby-Frodingham generally operate with a **V** stockline, but from observations on one particular furnace it was considered that smoother operation might be achieved with an **M**-shaped stockline. It was already known that a considerable reduction in the diameter of the bell relative to the diameter of the throat would produce an **M** stockline, but experiments showed that such a small bell would be needed that the hopper size to go with it would be quite inadequate for rapid charging of the furnace. Accordingly, trials with models were made to determine the best method of altering the stockline profile from **V** to **M** shape.

Aim of Experiment

To produce an **M** stockline and to study the effect on blast-furnace performance.

Experimental Procedure

As a result of the model trials, an **M** stockline was achieved by fitting a skirt or deflector ring at the base of the bell (*see* Fig. 1). The skirt was then fitted to the bell of No. 8 furnace (14 ft. 6 in. dia. hearth), and it was confirmed that an **M** stockline was obtained before blowing-in.

The furnace was blown-in in the normal way, but was treated rather more gently than usual for the first week or so. This was primarily because it was not a new furnace and it was necessary to work down the level of the bottom. Difficulties, however, were soon encountered, and the bell was modified after five weeks' operation. It appeared that the **M** stockline obtained was too great a departure from the normal **V** stockline, and that an intermediate stage was desirable. As a result of further model trials, this stage was obtained by cutting off the upper half of

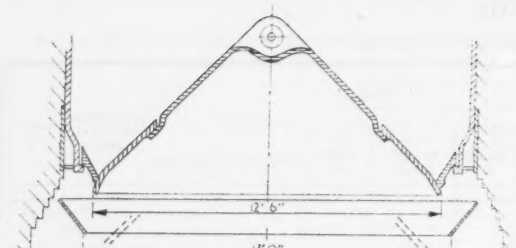

Fig. 1—The skirted bell (*Scale:* 1 in. = 6 ft.)

the skirt so that, of the material flowing from the bell, approximately half went over the skirt and half was diverted by the skirt. Trials were continued for a further four weeks.

Results

The operation for the first nine days was typical of a newly blown-in furnace, but subsequently it became extremely difficult. Stock descent was increasingly interrupted and, in addition, periodic 'messes' so decreased the hearth heat that great difficulty was encountered in running either iron or slag.

The furnace would not operate at all with a high percentage of sinter in the burden, or with a blast heat higher than 300–350° C., which is 150° C. lower than the average for Appleby-Frodingham practice.

As a result of these operating troubles, the coke consumption remained high and the output of iron low. The skirt was, therefore, modified and the furnace was blown for a further four weeks ; but little improvement was obtained, so the skirt was removed and the **V** stockline was re-adopted.

Conclusions

The skirted bell promoted an **M** stockline but apparently concentrated all the fines in a tight annulus below the lip of the skirt, which virtually sealed off the furnace into two portions and prevented smooth operation.

It is conceivable that, under the prevailing conditions, there were virtually three separate and distinct stock columns, each attempting to move downwards at different speeds and giving rise to periodic messes.

It should be emphasized that the skirted bell was an attempt to adapt a blast-furnace to use coke of indifferent quality, but it appears that under all conditions Appleby-Frodingham practice demands a stock column in which the centre is more permeable and is moving faster than the outer periphery.

(7) THE EFFECT OF STEAM IN THE BLAST

Although the reaction $C + H_2O = H_2 + CO$ between carbon and steam is endothermic, requiring approximately 4700 B.Th.U./lb. of carbon, it has been claimed that greater economy can be achieved in a blast-furnace by the introduction of steam in the blast, owing to accelerated reduction of iron oxides and smoother operation. It has also been stated that the loss of hearth heat can be compensated for by additional blast temperature.

Aim of Experiment

To study the effect of mixing steam in the blast, with particular reference to a 'sticking' furnace.

Experimental Procedure

The experiment was carried out in two parts. (i) Steam was introduced at the normal purging point on the cold-blast main near the snort valve, *for a period not exceeding* 30 *minutes*. Part of the steam was preheated by the stoves and part by-passed the stoves through the cold-blast mixing main. During the period in which steam was used in this way, the blast temperature was 500–550° C., in accordance with the usual practice. (ii) Steam was introduced into the blast main immediately after the blowing engine (so that steam which passed through the cold-blast mixing main was not preheated) *for a period of three weeks* (July 16th–August 5th, 1950). The amount of steam introduced was measured, and was regulated to give 6 grains/cu. ft. of blast, which was equivalent to 1·8% of the blast volume.

Table XIV
DETAILS OF TESTS

Week Ending	Charges	Iron Output, tons/week	Ore/Coke Ratio	Coke Consumption, cwt./ton	Average Analysis, %		Weight of Ore per Charge, lb.	Blast Temperature, ° C.	No. of Dirty Casts
					Si	S			
Normal Operation									
24/6/50	547	1320	2·41	26·86	0·81	0·073	19,140	550	5
1/7/50	598	1340	2·24	27·85	0·86	0·095	18,440	500	6
8/7/50	599	1220	2·04	28·19	0·85	0·079	17,470	480	6
Average	581	1290	2·20	27·63	0·81	0·083	18,350	510	5·66
Steam in Blast									
22/7/50	564	1200	2·13	31·51	1·02	0·107	18,220	550	9
29/7/50	606	1300	2·15	29·18	0·98	0·106	17,910	550	7
5/8/50	639	1280	2·00	29·33	0·89	0·084	16,660	580	4
Average	603	1260	2·09	30·01	0·96	0·099	17,630	560	6·66

Results

Data comparing the three weeks before the introduction of steam with the three weeks in which steam was used are shown in Table XIV.

It was observed, generally, that when steam was introduced for short periods a furnace would check more easily, and for a short time afterwards there would be some improvement in the blast volume. There was no increase in the coke consumption or in the amount of ' shoddy ' made.

When steam was introduced for long periods, the condition of the furnace was little different from that of normal practice, and no ' veiling over ' of the tuyeres was observed. During casting, however, there was a tendency for the iron and the roughing slag not to separate, although in three weeks, out of a total of 84 casts, only 20 were classed as ' dirty.'

Conclusions

The performance figures indicate that little benefit was derived from using steam over a prolonged period, but that there was a definite increase in the amount of coke used, and a reduction in the ore/coke ratio. The use of steam for short periods of up to 30 min. showed that some benefit could be derived on a furnace which was very tight and was proving difficult to check.

Section II—WORKINGTON BLAST-FURNACE TRIALS

The Workington plant is an integrated iron and steel works comprising coke ovens, blast-furnaces, acid Bessemer steelplants, and rolling mills. There are three blast-furnaces, but normally only two are in blast together. Each of the three furnaces has a different hearth diameter ; No. 2 is 20 ft. dia., No. 3 is 16 ft. 6 in. dia., and No. 4 is 15 ft. dia.

Molten metal from the blast-furnaces is transferred to the Bessemer shop, and the productivity of the steelworks is dependent upon an adequate supply being maintained. As an integrated plant, the whole economy of the works depends upon a proper balance being maintained between the rate of production at the coke ovens, the blast-furnaces, and the steelworks. For this reason, large-scale experimental work which would involve any risk of interrupting the normal levels of production cannot be undertaken.

Any work of this nature which has been carried on has therefore required most careful consideration. Where possible, it has been preceded by small-scale experiments such as those involving possible deterioration of coke quality ; or when operating procedure has been altered, the effects of which were in any doubt, such alterations have been introduced in easy stages.

The experiments at Workington have been largely concerned with improving coke quality and with burden preparation. Of necessity, therefore, trials have not been made over a long period, because of the large tonnage of materials to prepare. The actual operating data are thus always considered along with the blast-furnace operatives' opinion as to how the furnace worked during the test.

When the findings of a large-scale short-term trial have been adopted for general practice, the results have provided further data from what might be termed a continuous full-scale trial. This data has been analysed statistically, and in general confirms the findings of the original trials.

The ' worth-whileness ' of all that has been done is best demonstrated by the results now obtained from the furnaces. For 1948, the coke consumption per ton of hematite iron was 19·44 cwt., whereas for 1950 the average was 16·88 cwt., with a record low figure of 15·77 cwt. in one week at No. 3 furnace.

Output has at times been restricted by the shortage of imported ore, but in December, 1950, the two smaller furnaces gave a combined output of 6700 tons weekly, which was at least 500 tons in excess of that previously obtained. In this connection it should be pointed out that, because of restricted ore supplies, the furnaces could not be driven to full capacity. For this reason, the effect on output of any experimental change could not be measured quantitatively.

(1) THE EFFECT ON COKE QUALITY OF THE INTRODUCTION OF A LOW VOLATILE COAL INTO THE BLEND

It was recognized that the quality of the coke being made at the coking plant fell short of what was considered to be the minimum for good furnace operation. The coal from which the coke was made was drawn from two coalfields, and over the years the proportions had changed, to the detriment of the resulting coke. Both coals had a fairly high volatile content, and earlier experience had shown that the introduction of a proportion of low volatile coal enabled the rate of coking to be substantially increased without any deterioration in coke quality. On the basis of this experience it was decided to experiment with similar additions to the blend, to see if coke quality could be improved under optimum carbonizing conditions.

To this end, use was made of a small experimental oven ; the comparative results obtained justified a large-scale trial.

Aim of Experiment

To determine whether the introduction of a low volatile coal into the blend would produce a coke of better quality, as measured by its performance in the blast-furnaces.

Experimental Procedure

Samples of various low volatile coals were obtained and were blended, in varying proportions, with the standard mixture of high volatile coals for carbonizing in the experimental oven, which had a capacity of 500 lb. of coal. On the basis of the physical properties of the resultant coke, as ascertained by the shatter test, it was decided to proceed with a large-scale trial using an addition of approximately 10% of the low volatile coal. The carbonizing rate would be held at that normally applied to the standard blend.

The coal was carbonized in 16-in. Becker ovens, and the coke was screened at the coke plant before being delivered to the blast-furnace bunkers. No further screening took place.

During the trial period, the operation, both at the coke ovens and at the blast-furnaces, was carefully watched. The data obtained were analysed and were compared with those for periods before and after the test week.

Table XV
SHATTER TEST RESULTS

Variable	Shatter, %					
	4 in.	3 in.	2 in.	1½ in.	1 in.	− ½ in.
Half Section Coke						
No low volatile. Average shatter for previous five weeks	0·8	21·3	60·7	79·5	91·5	3·44
Low volatile. Average shatter during trial week	4·3	26·5	64·3	81·5	96·9	3·06
No low volatile. Average shatter for subsequent five weeks	2·9	22·6	60·6	78·8	91·2	3·28
	+ 2 in.		2 in.	1½ in.		− ½ in.
+ 2-in. Coke						
Without low volatile	74·82		63	80		3·17
With low volatile	78·65		68	86		2·08

Results

The experimental oven tests initially performed indicated that the addition of 10% of low volatile coal produces an improvement in the coke quality, increasing the 2-in. and 1½-in. shatter index by 3·0–3·5%, and reducing the − ½-in. index by 0·57%.

The large-scale trial of the addition of approximately 10% of low volatile coal to the blend resulted in an improvement in the shatter test figures, by about 3 points on the 2-in. index, 2 points on the 1½-in. index, and a reduction of 0·38% on the − ½-in. index.

It is the custom at Workington to use full 'half section' pieces of coke for the shatter test, as it is believed this gives a better indication of the basic strength of the coke. A much greater improvement can be observed for the tests carried out on the + 2-in. coke.

The shatter test comparisons are given in Table XV.

The coke produced during the large-scale trial, when used at the blast-furnaces, resulted in improved working and a reduction of 0·4 cwt./ton in coke consumption (*see* Fig. 2), despite operational conditions which militated against full advantage being taken of the better coke.

Conclusions

The results of the trials proved that low volatile coal blending would effect improvements in coke quality and reduction in coke consumption. It was arranged, therefore, that low volatile coal blending would be adopted as standard practice, and the effect of the coke on blast-furnace performance over a longer period was closely observed. The improvements were even greater than the experiments had suggested.

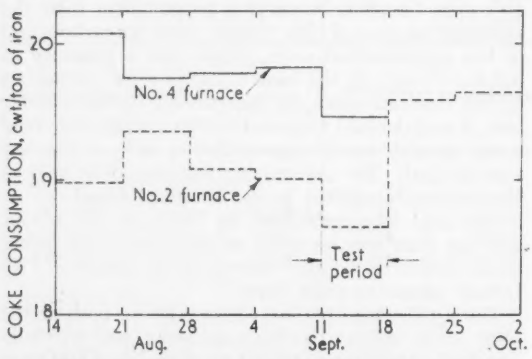

Fig. 2—The effect on coke consumption of using coke made from a blend containing low volatile coal. Weekly data from 14/8/48 to 2/10/48

The favourable changes in shatter test of the coke over a longer period have been calculated to average as follows :

2 in.	1½ in.	− ½ in.
5·0%	5·0%	0·5–0·7% (decrease)

The furnace performance was improved, and the coke consumption was reduced by about 0·5 cwt./ton, as a direct result of the improved coke. Also, the better coke was partially responsible for the improved furnace practice, as it enabled reduced slag volumes to be used and more sinter to be carried in the burden. Furnaces have driven much more freely, and their iron-making capacity has been increased.

(2) THE EFFECT OF BLENDING GROUND COKE BREEZE IN THE COAL BLEND

The blending of finely ground coke breeze into the coal blend has long been known to increase the 1½-in. shatter index of the coke produced from local coals. The authors' experience with the blast-furnaces has indicated that the − ½-in. shatter index is vitally important, as it is a measure of the abradability. Considerable concern has been felt from time to time regarding the effect of coke breeze on abradability, but the general opinion appears to be that if the breeze is sufficiently finely ground, then no increase in abradability will be found with breeze additions up to 5%.

Aim of Experiment

To ascertain whether the addition of coke breeze to the coal blend would improve the coke quality to the same extent as did the addition of 10% of low volatile coal.

Experimental Procedure

Initial tests to obtain indications of the effect of coke-breeze blending on the mechanical properties of the resultant coke were made on small quantities of coal in the experimental oven. The indications obtained from these tests were favourable, and it was

decided to run a large-scale test by carbonizing breeze-blended coal on a production scale, and charging to the blast-furnaces. For this purpose, 80 tons of finely crushed coke breeze were purchased from Durham and, to obtain the maximum information, portions were used in five different blends, as follows :

Blend 1—Normal blend without low volatile coal + 3 % of breeze
Blend 2—Normal blend without low volatile coal + 4 % of breeze
Blend 3—Local blend without low volatile coal + 4 % of breeze
Blend 4—Local blend + 5 % low volatile coal + 3 % of breeze
Blend 5—Normal blend + 5 % low volatile coal + 3 % of breeze.

The special coke produced was loaded into wagons and was delivered to one furnace (No. 3, 16 ft. 6 in. dia. hearth) only, where it constituted about 30% of the coke charged. The complete operating details are shown in Tables XVI and XVII.

Owing to the small amount of specially blended coke available, and to the fact that only 30% was used in the charge, reports on visual observations, only, of the coke were made at the blast-furnaces.

Results

The Experimental Oven Tests—These tests indicated that coke-breeze blending was beneficial and compared very favourably with low volatile coal as a blending agent. The shatter test figures, %, obtained from experimental oven coke are as follows :

	2 in.	1½ in.	−½ in.
Basic blend	66·8	84·5	3·27
Basic blend + 5 % of coke breeze	77·0	88·3	3·25
Basic blend + 7½ % of coke breeze	81·1	89·8	3·33
Basic blend + 10 % of low volatile	76·4	87·5	3·03

The Large-Scale Oven Test—This gave the following results (*see* Table XVIII) :

(i) Addition of 4% of breeze to both local coals and mixed coals improved the 2-in. and 1½-in. shatter index by 7% and 3–6%, respectively. There was no evidence to suggest that the abradability was worse.

(ii) Breeze addition compared favourably with the addition of 10% of low volatile coal.

(iii) The coke size was generally larger than that obtained by the use of low volatile coal.

Conclusions

The tests, whilst being rather limited in their scope, did provide useful information, and proved the practicability of breeze blending for the maintenance of good coke quality. A detailed study of the effect of breeze-blended coke on blast-furnace performance

Table XVI
EXPERIMENTAL OVEN TESTS

Test No.	Blend	Shatter Test, %		
		2 in.	1½ in.	− ½ in.
Trial *A*				
37	Basic blend	75·1	86·6	2·90
38	Basic blend + 4% of coke breeze*	81·5	90·4	3·00
Trial *B*				
102	Basic blend (Local N.E.)	66·6	84·2	3·55
103	,, ,, ,, ,,	67·1	84·8	2·98
	Average	66·8	84·5	3·27
106	Basic blend + 5% of coke breeze	76·7	87·5	3·50
107	,, ,, ,, ,, ,, ,, ,,	77·2	89·1	3·00
	Average	77·0	88·3	3·25
108	Basic blend + 7½% of coke breeze	81·1	89·8	3·33
114	Basic blend (including N.E., as Test No. 102, + 3% of breeze)	72·1	87·0	2·85
Trial *C*				
109	Local blend	64·9	81·7	2·90
111	,, ,,	65·8	81·2	3·50
	Average	65·3	81·4	3·20
112	Local blend + 5% of breeze	76·7	87·2	3·10
Trial *D*				
121	Basic blend (including N.E.)	73·9	84·5	4·40
122	,, ,, ,, ,,	72·2	84·4	3·40
	Average	73·5	84·5	3·90
123	Basic blend + 10% of low volatile*	77·9	88·3	3·37
125	,, ,, ,, ,, ,, ,, ,,	74·9	86·8	2·70
	Average	76·4	87·5	3·03

Chemical Analysis :	Moisture, %	Ash, %	S, %	P, %	Volatile Matter, %
Coke breeze	9·0	12·20	0·88	0·015	8·0
Low volatile coal	6·2	9·20	0·96	0·024	17·8

Table XVII

LARGE-SCALE TESTS

Variable	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
Screen Analyses of Breeze, %					
+ 5 B.S.S.	0·60	nil	0·10	nil	nil
− 5 + 25 B.S.S.	34·87	31·15	30·08	31·74	25·20
− 25 + 60 B.S.S.	34·35	34·90	33·62	33·80	32·75
− 60 + 120 B.S.S.	17·65	17·92	19·25	19·84	20·30
− 120 B.S.S.	12·53	16·03	16·95	14·62	21·75
Screen Analyses of Coal Blend, %					
+ ¼ in.	3·5	3·6	6·25	3·60	5·90
− ¼ in. to + ⅛ in.	13·3	12·75	14·85	12·60	11·60
− ⅛ in.	83·2	83·65	78·90	83·80	82·50
Coal Blend as Charged, %					
North East, 1st Class	8·25	15·55	..	..	14·0
North East, 2nd Class	22·70	13·30	..	..	20·0
Local	65·80	67·15	96·0	92·0	58·0
Breeze	3·25	4·00	4·0	3·0	3·0
Low volatile	..	..	..	5·0	5·0
Analyses of Blend					
Moisture, %	8·9	7·35	9·55	10·0	6·5
Ash, %	8·42	8·97	9·37	8·55	9·85
Sulphur, %	1·60	1·57	1·71	1·62	1·40
Phosphorus, %	0·0134	0·0104	0·0138	0·0155	0·0114
Volatile matter, %	32·7	31·55	32·75	32·9	29·3
Swelling No.	6	5½	6	7	7½
Oven Schedule per Shift, hr.	28	29	29	29	29
Carbonizing Time, hr. min.	18.13	17.53	17.55	17.41	17.44
Average Temperature, °C.	1289	1293	1295	1293	1288
Coke Analyses					
Moisture, %	1·55	1·50	1·10	0·90	0·80
Ash, %	12·19	11·35	12·77	11·78	13·14
Sulphur, %	1·39	1·36	1·46	1·36	1·25
Phosphorus, %	0·0183	0·0142	0·0180	0·0207	0·0162
Volatile matter, %	0·78	0·78	0·89	0·69	0·74
Carbon, %	85·47	86·36	85·23	86·63	85·31
Coke Porosity					
Specific gravity	1·926	1·902	..	1·923	1·931
Apparent specific gravity	1·066	1·039	..	1·008	1·050
Apparent porosity	40·1	38·1	..	42·7	40·6
Total porosity	44·7	45·3	..	47·6	45·6
Shatter Test (Half Section Coke)					
4 in.	4·0	1·7	4·8	36·20	8·4
3 in.	28·3	28·6	31·3	73·40	36·8
2 in.	66·4	71·1	72·2	81·6	74·4
1½ in.	81·2	83·6	84·5	94·4	86·3
1 in.	82·3	92·9	92·95	93·3	94·1
½ in.	97·15	97·16	97·01	6·89	97·4
− ½ in.	2·85	2·84	2·99	3·11	2·60
Coke Bulk Density, lb./cu. ft.	29·45	29·57	29·31	28·25	30·17
Screen Test of Coke ex Wharf, %					
+ 4 in.	8·82	8·45	15·40	10·07	8·12
− 4 + 3 in.	32·82	39·59	39·38	30·39	39·74
− 3 + 2 in.	34·74	38·56	27·13	34·17	32·60
− 2 + 1½ in.	13·48	6·21	3·91	11·51	8·83
− 1½ + 1 in.	4·49	3·22	4·89	6·30	5·51
− 1 + ½ in.	2·36	1·61	3·24	3·60	1·94
− ½ in.	3·30	2·38	6·06	3·96	3·26
Screen Test of Coke after Screens, %					
+ 4 in.	6·40	2·98	4·89	nil	10·16
− 4 + 3 in.	31·14	37·16	39·08	42·45	41·10
− 3 + 2 in.	41·42	40·88	36·36	39·60	34·94
− 2 + 1½ in.	12·47	9·20	11·30	11·39	9·04
− 1½ + 1 in.	5·96	6·65	5·88	5·13	3·41
− 1 + ½ in.	1·42	2·00	1·61	0·72	0·61
− ½ in.	1·16	1·15	0·90	0·71	0·76
Shatter Test on +2-in. Coke after Screens, %					
4 in.	2·4	3·25	1·50	nil	1·25
3 in.	22·2	21·50	24·75	29·50	27·55
2 in.	67·7	67·40	75·90	76·30	79·90
1½ in.	84·9	85·40	86·25	88·30	89·8
1 in.	93·7	93·65	94·50	94·80	95·55
½ in.	97·25	97·37	97·75	97·50	97·75
− ½ in.	2·75	2·63	2·25	2·50	2·25

Table XVII—*continued*

Variable	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
Screen Test of Coke at Furnace End, %					
+ 4 in.	nil	nil	2·10	3·29	8·07
− 4 + 3 in.	26·82	22·35	22·15	19·02	28·83
− 3 + 2 in.	44·87	50·12	53·35	44·50	44·33
− 2 + 1½ in.	16·39	14·81	15·46	18·42	10·68
− 1½ + 1 in.	7·22	7·90	1·81	9·57	4·07
− 1 + ½ in.	2·41	2·47	2·10	2·63	1·53
− ½ in.	2·29	2·35	3·03	2·57	2·49
Shatter Test on +2-in. Coke at Furnace End, %					
4 in.	nil	nil	1·0	4·3	7·6
3 in.	10·5	12·1	16·3	21·4	31·8
2 in.	73·8	69·9	80·2	69·9	75·4
1½ in.	86·8	87·7	90·3	88·8	85·0
1 in.	94·8	94·7	94·7	96·2	95·9
½ in.	97·17	98·13	98·25	98·25	98·08
− ½ in.	2·83	1·87	1·75	1·75	1·92
Coke Bulk Density, lb./cu. ft.	29·88	32·25	28·94	28·13	30·88

Table XVIII

SHATTER TEST RESULTS FOR LARGE-SCALE TESTS

Test	Breeze-Blended Coke, %	Coke from Basic Coals Only, %		Coke from Basic Coals + 10% of Low Volatile, %	
Blend 1					
4 in.	4·0			3·0	
3	28·3			28·7	
2	66·4	61·7		67·1	
1½	81·2	79·5	Average Coke	83·7	
1	92·3		3/10/48 to	93·3	
½	97·15		4/12/48	96·92	
− ½	2·85	3·16		3·08	
Blend 2					
4 in.	1·7			5·1	
3	28·6			33·7	
2	71·1	63	Has more N.E.	70·8	
1½	83·6	80–81	Grade I than	84·5	
1	92·8		Blend 1, there-	94·50	
½	97·19		fore slightly	97·67	
− ½	2·84	3·00	better shatter	2·33	
Blend 3					
4 in.	4·8			Two Tests	
3	31·3				
2	72·2		60–63	67·9	66·1
1½	84·5		78–80	83·5	81·7
1	92·9				
½	97·01				
− ½ in.	2·99		3·25–3·90	2·87	2·87
Blend 4					
4 in.	6·2				
3	33·4				
2	71·6				
1½	84·4		As above	As above	
1	93·3				
½	96·89				
− ½	3·11				
Blend 5					
4 in.	8·4			nil	
3	36·8			28·0	
2	74·4	63		69·3	
1½	86·3	80–81	Has more N.E.	85·8	
1	94·1		Grade I than	94·3	
½	97·40		Blend 1; more	97·08	
− ½	2·60	3·0	like Blend 2	2·92	

was not possible, owing to the limited quantity produced, and because this only comprised 30% of the coke charge. There were no indications from either the furnace operating data or the actual furnace operation that the coke was any different from low volatile blended coke.

It was decided that, at a later date, if possible a sufficient quantity of breeze should be obtained to permit a run of about two weeks on breeze-blended coke. Its effect on blast-furnace operation and performance could then be studied, and the economics of breeze blending as normal procedure could be ascertained.

(3) THE EFFECT OF A HIGH PERCENTAGE OF SINTER IN THE CHARGE

The preparation of the burden has long been recognized as a desirable, and even necessary, feature of blast-furnace practice. Ore preparation normally includes the crushing and screening of ores, and the most important method of utilization of ore fines is that of sintering. The charging of screened ores and sinter, as compared with unscreened ores, has proved beneficial in the past, and therefore an investigation into the merits of using a high percentage of sinter was planned. The trend towards increasing percentages of fines in foreign ore cargoes, and the possibility of reduction of sulphur content of fines by sintering, emphasized the importance of this knowledge.

Aim of the Experiment

To ascertain the effect on blast-furnace performance of increased proportions of sinter in the charge, and to determine whether decreased coke consumptions would result.

Experimental Procedure

The test was made from 20th August to 10th September, 1949, during which time a high percentage of sinter was charged to No. 2 furnace. To permit this high sinter charge to be made, a stock of sinter of 2250 tons was built up prior to the test, and the test period was planned to coincide with the production of spiegel on the other furnace, which used very little sinter. The percentage of sinter being charged was worked up from the normal practice in increments of approximately 5%, until, during part of the second and third weeks of the test, 67% of sinter was being charged.

Details of the furnace operation during the test were compared with those for periods before and after the test.

The furnace on which the test was performed had a 20-ft. dia. hearth, and was charged by scale car, double skip hoist, and McKee distributor.

The sinter plant from which the sinter was obtained was a two-pan Greenawalt plant, each pan being 22 ft. 8 in. long × 10 ft. wide, the depth being adjustable from 12 to 16 in., as required. Sintering normally occurred at suctions of 35–45 in. W.G., and after sintering, preliminary air cooling, and screening, the $+\frac{1}{8}$-in. material was water-cooled and conveyed to the stockpile. The sinter was then transported to the furnace bunkers by the ore bridge and transfer car.

Results

A summary of the operating conditions and performance before, during, and after the test is given in Table XIX.

During the entire period under review, furnace conditions, apart from the percentage of sinter in the charge, have varied, particularly the slag volume and the blast temperature. To show the effect of increase in sinter more clearly, correction must be made for these other variations; using the test period as the base, the corrected coke consumptions become:

8 weeks before test	18·10 cwt.
3 weeks test period	17·21 ,,
8 weeks after test	17·55 ,,

There is little doubt that an increase in the percentage of sinter had improved the coke consumptions that were hitherto obtained. The 8 weeks following the test gave results better than the 8 weeks before.

During the first week of the test period the coke consumption was 17·76 cwt./ton, due to the lag in the furnace reacting to the changes. Had the trial been for a longer period, the possibility is that the furnace coke consumption would have been about 17·00 cwt. During the second week of the trial, the coke consumption was 16·89 cwt./ton, and was the

Table XIX

OPERATING CONDITIONS AND PERFORMANCE

Burden	Averages for 8 Weeks 25/6/49–20/8/49	Averages for 3 Weeks 21/8/49–10/9/49	Averages for 8 Weeks 11/9/49–5/11/49
Sinter, %	39·58	63·31	43·75
Hard ores, %	31·41	21·67	32·03
Soft ores, %	26·98	12·73	21·95
Scale, scrap, etc., %	2·03	2·29	3·52
Weekly iron production, tons	3587	3755	3807
Weekly coke consumption, cwt./ton	18·37	17·21	17·34
Slag volume, cwt./ton	8·84	8·07	7·92
Si in iron, %	2·29	2·23	2·22
Blast pressure, lb./sq. in.	11·04	11·57	11·67
Blast volume, cu. ft./min.	44,338	42,843	43,630
Blast temperature, °F.	1150 (596° C.)	1084 (584° C.)	1136 (613° C.)

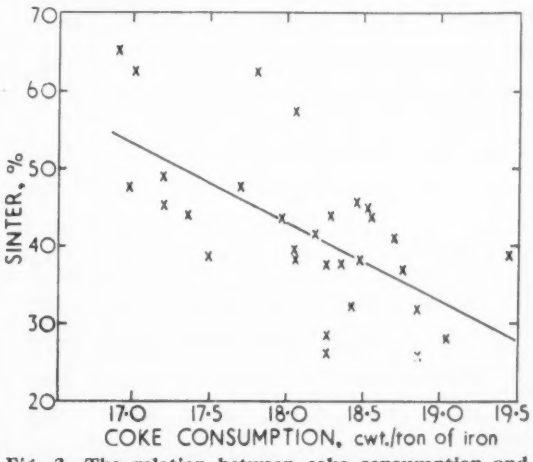

Fig. 3—The relation between coke consumption and the percentage of sinter in the charge, for No. 2 furnace. Weekly data from 27/3/49 to 22/10/49

lowest in the whole of the 19-week period. There seems, therefore, little doubt that an increase in the percentage of sinter in the burden resulted in a reduction of coke consumption.

At the same time, a word of warning is necessary. The increases in sinter consumption were made at the expense of screened ore, and consequently the beneficial effect would probably be less in this case than if it were replacing run-of-mine ore unscreened.

Complete operating details are shown in Table XX and Fig. 3.

Conclusions

The results of the test indicate the advantages of the inclusion of high percentages of sinter in the charge, in obtaining lower coke consumptions. It was also considered that the limiting percentage of sinter had not been reached during the test, and that the sinter charge could have been increased beyond 67%. It is obviously of vital importance that the physical quality of the sinter should be maintained at a constantly high standard when a large percentage is being charged to the furnace.

In support of the test results, Fig. 3 shows the relationship between the percentage of sinter in the charge and the coke consumption of No. 2 furnace, over a period of eight months. The correlation between the two factors is statistically significant.

(4) AN ASSESSMENT OF THE MAXIMUM COKE-BURNING RATE OF A FURNACE

In the search for a suitable yardstick for blast-furnace performance, the formula of Owen Rice has attracted the authors' attention. This formula gives

Table XX

WEEKLY BLAST-FURNACE DATA BEFORE, DURING, AND AFTER TEST

Week Ending (1949)	Burden				Iron Production, tons	Coke Consumption, cwt./ton	Slag Volume, cwt./ton	Blast Pressure, lb./sq. in.	Blast Volume, cu. ft. min.	Blast Temperature, °F.	Si in Iron, %
	Hard Ores, %	Soft Ores, %	Sinter, %	Scale, Scrap, etc., %							
July 2	31·99	39·55	25·76	2·70	3493	18·86	8·80	10·96	44,111	1119 (604° C.)	2·26
9	26·82	25·59	43·62	3·97	3647	18·55	9·08	11·80	44,857	1086 (586° C.)	2·25
16	34·88	25·87	36·62	2·64	3678	18·76	9·51	11·45	45,595	1100 (593° C.)	2·48
23	37·69	22·34	37·40	2·57	2874	18·26	8·61	12·22	47,357	1127 (608° C.)	2·36
30	30·31	23·70	43·24	2·75	3826	17·97	8·61	11·76	48,429	1168 (631° C.)	2·50
Aug. 6	38·71	31·52	28·53	1·24	3400	18·26	8·56	9·20	43,143	1068 (575° C.)	2·40
13	30·33	25·68	43·99	nil	3288	18·28	8·48	9·70	39,571	1073 (577° C.)	2·04
20	20·08	22·56	57·36	nil	3493	18·05	9·04	11·12	41,643	1096 (591° C.)	1·97
Average for 8 weeks	31·41	26·98	39·58	2·03	3587	18·37	8·84	11·03	44,338	1105 (596° C.)	2·29
Sinter Trial											
Aug. 27	20·94	15·18	62·21	1·68	3611	17·76	8·38	11·76	42,100	1094 (590° C.)	2·25
Sept. 3	21·24	10·99	65·04	2·73	3859	16·89	8·30	11·76	43,286	1093 (590° C.)	2·18
10	22·79	12·16	62·61	2·44	3794	17·01	7·55	11·20	43,143	1065 (574° C.)	2·25
Average for 3 weeks	21·67	12·73	63·31	2·29	3755	17·21	8·07	11·57	42,843	1084 (585° C.)	2·23
Sept. 17	35·14	18·35	43·77	2·54	3721	17·35	7·66	10·43	43,467	1009 (543° C.)	2·51
24	27·83	24·29	45·34	2·54	3763	17·19	8·19	10·98	42,572	1115 (602° C.)	2·19
Oct. 1	31·40	17·20	48·95	2·45	3737	17·19	7·58	11·60	43,572	1176 (635° C.)	2·31
8	28·15	21·84	47·60	2·40	3829	17·63	8·86	11·69	43,470	1165 (629° C.)	2·11
15	32·94	25·40	38·36	3·30	3678	17·49	7·97	11·41	43,000	1151 (622° C.)	2·15
22	32·56	14·22	47·79	5·14	3909	16·96	7·97	12·09	43,333	1175 (635° C.)	2·10
29	30·99	24·10	39·65	5·26	3954	11·33	8·33	12·48	47,714	1163 (628° C.)	2·18
Nov. 5	37·24	30·21	38·55	5·00	3867	17·59	7·80	12·70	44,905	1136 (613° C.)	2·26
Average for 8 weeks	32·03	21·95	43·75	3·52	3807	17·34	7·92	11·67	43,630	1136 (613° C.)	2·22

Table XXI
DAILY BLAST-FURNACE DATA

Date, (July, 1949)	Iron Production, tons	Coke Used, tons	Average Blast Volume, 1000 cu. ft./min.	Average Blast Pressure, lb./sq. in.	Average Blast Temperature, °F.	Burden						Ore/Coke Ratio
						Cumberland Ore, %	Sinter, %	Kiruna, %	Stripa, %	Scale, %	Other Ores, %	
Before Test												
11	515·4	486·1	45	11·0	1100	18·5	41·0	11·0	...	2·5	27·0	1·90
12	544·8	492·0	46	10·5	1100	18·3	40·6	10·9	5·9	2·5	21·8	1·92
13	507·4	468·0	46	...	1100	18·3	21·8	14·4	6·4	2·5	36·6	1·92
14	514·7	516·0	47	12·5	1100	18·3	32·7	18·3	5·9	2·5	22·3	1·92
15	572·8	513·0	46·5	12·0	1080	17·3	32·7	20·3	4·9	2·5	22·3	1·92
16	527·6	504·0	45·3	12·3	1100	17·3	32·7	20·3	4·9	2·5	22·3	1·92
17	294·0	291·0	44	...	1100	12·1	33·3	19·3	8·0	2·5	24·8	1·89
18	582·0	521·9	46·5	12·0	1000	13·6	33·3	19·3	8·0	2·5	23·3	1·89
19	543·9	525·0	47	12·5	1100	11·6	38·4	19·3	8·0	2·5	20·2	1·89
Test Period												
20	574·3	540·0	49	12·0	1125	10·6	41·8	19·3	7·1	2·5	18·7	1·89
21	650·9	558·0	49	12·0	1150	9·6	41·8	19·3	3·5	2·5	23·3	1·89
22	630·7	567·0	50	12·5	1150	8·6	41·8	19·3	4·5	2·5	23·3	1·89
23	654·5	582·0	48·4	13·2	1200	9·6	41·8	20·3	3·5	2·5	22·3	1·89
24	601·4	552·0	51	12·5	1250	8·6	42·9	20·2	3·5	2·5	22·3	1·89
25	629·5	570·0	52	13·5	1200	8·6	42·9	20·2	4·5	2·5	21·3	1·89
26	594·7	531·0	48	12·0	1150	8·8	44·1	16·6	6·2	2·6	21·7	1·84
After Test												
27	569·2	525·0	49	11·5	1150	8·7	43·6	16·4	6·1	2·6	22·6	1·86
28	546·3	501·0	46	10·5	1150	8·8	33·6	21·8	5·2	2·6	28·0	1·84
29	261·3	246·0	45	...	1125	8·8	33·6	21·8	5·2	2·6	28·0	1·84

the daily coke-burning rate as 6300 lb. per square foot of the annular space, six feet from the tuyeres.

Examination of our records showed that on several furnace campaigns the Rice coke-burning rate had, at some time or other, been achieved. Prior to 1949, coke quality was poor, resulting in the maximum output of No. 2 furnace being much lower than that indicated by the Rice formula ; but this was of little importance, owing to a shortage of raw materials. Improvements made in the coke quality indicated that, if the raw materials were available, the furnace output would probably be greater than hitherto. Accordingly, a trial was organized in which the output of No. 2 furnace was increased for a period of a week.

Aim of the Experiment

To determine the output that could be obtained from No. 2 furnace when blown to the limit of the existing blower.

Experimental Procedure

The experiment was planned during a period when supplies of raw materials were available and when coke quality was reasonably good. The furnace on which the trial was made had a 20-ft. dia. hearth. This furnace was blown by a turbo-blower rated at 45,000 cu. ft./min. The blast volume was then gradually increased until 52,000 cu. ft./min. were being blown.

Results

When blown to the limit of the blower capacity, the furnace made 4335 tons of iron from 3900 tons of coke in seven consecutive days, and thus achieved 84·4% of the Rice coke-burning rate. Furnace operation was good, and there was little doubt that larger outputs and higher coke-burning rates could have been obtained had more raw materials and more wind been available. Details of the results are given in Table XXI.

Conclusions

For a furnace with a 20-ft. dia. hearth the Rice coke-burning rate is 4620 tons/week. In the experiment 3900 tons of coke were burned in one week, which is 84·4% of the Rice rate. There was every indication that the furnace would have taken more wind had it been available.

It is realized that as the coke consumption is reduced the amount of material that has to pass through the furnace for a given coke-burning rate is increased, and that the lower the coke consumption the more difficult will be the attainment of the Rice rate.

Whether, in this instance, the Rice rate would have been achieved is difficult to say, but the test did indicate that with good quality coke and a well-prepared burden the furnace would produce more iron than had hitherto been expected.

Acknowledgments

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The Present Position of the Converter Process

ECONOMIC COMPARISON WITH OTHER STEELMAKING PROCESSES

By Dr.Mont. Ing. Bernhard Matuschka

SYNOPSIS

A comparison is made between the economic aspects of open-hearth and basic Bessemer steel production. It is shown that when slag is recovered the ingot costs for the two processes are about equal, provided that the open-hearth plant can work with 50% of scrap : for a works producing one-third basic Bessemer steel and two-thirds open-hearth steel, the costs are lower than for an entirely open-hearth works, if equal amounts of scrap are available.

Costs for blowing stahleisen are higher than those for an open-hearth plant, but in a works combining converters and open-hearth furnaces the total costs are about the same as for entirely open-hearth operation: when oxygen is used for blowing, a steel is obtained whose quality is equivalent to that of open-hearth steel, but at a price 5–10% higher. Steel made in an induction-heated converter would be as cheap as open-hearth steel, if the charge carried 50% of scrap.

The oxygen-blowing process and the induction-heated converter enable a great part of the manganese content of pig iron to be converted into a slag suitable for the preparation of ferro-manganese low in phosphorus, and offer the possibility of providing a large part of the ferro-manganese needs of Europe.

Introduction

THE revolution in the production of iron brought about by the Bessemer process is best indicated by the name given in German to the new product, ' Flusseisen '—liquid iron.

Since 1740, crucible-steel making has indicated how iron and steel may be made and poured in the molten state. The application of this complicated crucible process, however, was limited to special steels, such as alloyed and unalloyed tool steels, the special properties and the uses of which justified their relatively high cost. All other plain carbon steel was obtained in a semi-liquid, pasty condition from iron ore and pig iron, and was welded into large compact lumps of wrought steel. In spite of rapid improvements in the design of furnaces for making wrought iron, and of the increase in the daily furnace output from 7–10 tons to 15 tons or more, the production capacity for puddled steel was so much exceeded by the melting capacity of the new Bessemer converter that the economic merits of the new Bessemer process were soon no longer in doubt.

The use of the Bessemer process, however, advanced slowly in Europe because its metallurgical aspects had yet to be developed, and because the process was applicable only to certain types of low-phosphorus and high-manganese pig irons.

New features required special attention in the metallurgy of the Bessemer process. Considerably higher working temperatures were needed to teem the liquid steel, and these higher temperatures produced a more violent reaction between oxygen and the liquid steel, involving the danger of excessive oxidation unless protective materials, such as manganese, silicon, and phosphorus, were present in sufficient quantity. Otherwise, the effects of excessive oxidation had to be counteracted by the deliberate addition of deoxidants.

These factors, namely, the high temperatures involved, and the danger of excessive oxidation, not only restricted the general application of the new Bessemer process to particular kinds of raw materials, but also influenced the economic aspects of the converter process, affecting in particular the raw-materials costs.

The Bessemer process would never have developed as it did had there not been ore deposits in England and Sweden of extremely high manganese content, from which the high-manganese and high-silicon types of pig iron, later known as ' Bessemer pig,' were made.

This Bessemer pig iron was made in Sweden and, later, in Austria and the Siegerland, and although it became possible in later years to make good-quality steel in the Bessemer converter from pig irons that were lower in manganese and higher in silicon, the acid Bessemer process has been almost completely abandoned by the steel industry in favour of the open-hearth process and electric melting. The reasons were as follows : In the converter, it was not possible to work the large quantities of scrap arising from processes in the treatment of the steel, so that the scrap was almost valueless ; in the new open-hearth furnace, however, temperatures could be attained sufficiently high to melt pig iron and scrap together, and it was possible to melt not only scrap but also, particularly in England, to melt other qualities of pig iron, which were not suitable for the converter process. Use of the open-hearth furnace avoided the heavy losses due to ejects, and so improved the ingot production per ton of raw material.

During this period the Thomas converter process was developed ; this enabled high-phosphorus ores and pig irons to be worked in the converter, the process being cheapened by the production and sale of a very valuable by-product, phosphate slag (basic Bessemer slag), which has proved of great importance in agriculture. The acid Bessemer process in its original form has now practically died out, but the basic Bessemer converter retains its place in steelmaking even today. Basic Bessemer steel contains not only more phosphorus but also greater quantities of nitrogen, which make the mechanical properties of blown steel inferior to those of open-hearth steel. Successful efforts have been made in England, Sweden, and Germany to reduce the nitrogen content by treatment with iron ore and by alloying with alu-

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minium. Numerous experiments have also been made in the last few years, by blowing oxygen-enriched air, oxygen with steam or carbon dioxide, or pure oxygen, in the converter, and using increased quantities of scrap.

PRODUCTION DISTRIBUTION

The distribution of production between converter steel, open-hearth steel, and electric steel in Europe and the U.S.A. is approximately as follows :

	Acid and Basic Bessemer Steel, %	Open-Hearth Steel, %	Electric Steel, %
Europe	35	57	8
U.S.A.	5	90	5

The increasing use of the North Swedish and Minette high-phosphorus ores may in due course shift the balance in Europe more in favour of basic Bessemer steel. The present distribution of production corresponds approximately to the needs of the steel industry, which requires about one-third plain carbon steels. Future technical progress may, however, bring about another adjustment in favour of the increased use of the better-quality steels. In the U.S.A., the proportion of converter steel (acid Bessemer steel) is only 5%, mainly because of the type of ores available.

For individual European countries, the distribution is as follows :

	Acid and Basic Bessemer Steel, %	Open-Hearth Steel, %	Electric and Other Steels, %
Austria (today)	0	84	16
Austria (as reconstituted)	35	50	15
Belgium	85	14	1
Denmark	1	94	5
Finland	0	25	75
France	55	35	10
Great Britain	10	83	7
Italy	0	60	40
Luxemburg	99	0	1
Holland	0	96	4

Only France, Belgium, Luxemburg, and Germany produce any considerable proportion of basic Bessemer steel, owing to their use of the Minette ores of Lorraine. Apart from the 5% of basic converter steel produced in England at Corby and Ebbw Vale, the production in Europe is divided mainly between open-hearth and basic Bessemer steel, acid Bessemer steel, except in a few isolated works, having almost entirely disappeared from production.

GENERAL ECONOMIC ASPECTS

The essential condition for using the open-hearth process is that the price of scrap should be lower than that of pig iron, and that adequate quantities should be available. In the period after the introduction of the Bessemer process, abundant supplies of cheap scrap became available, making possible the building of large open-hearth steelworks all over Europe. It soon became necessary to work with higher proportions of pig iron in these plants, and the pig-and-ore process grew simultaneously with the pig-and-scrap process. Since then, market fluctuations in pig-iron and scrap prices have led to alternations between the two methods of open-hearth furnace operation. The pig-and-ore process, by which, as in the Talbot process, steel is made from high-phosphorus pig, has held its own. As in the basic Bessemer method, a valuable phosphate slag is obtained. An exception is provided by those countries (*e.g.*, Sweden, Austria, and Russia), in which the steelmaking industries are based on large domestic deposits of ore specially suitable for the open-hearth furnace, and to which scrap has to be imported from abroad.

A certain equilibrium has been reached in the market for scrap, although this was disturbed by the two world wars. After the First World War, just as after 1945, there was a superfluity of scrap. Rolmann, of Geneva, has calculated that the following proportions of scrap have been and will be used in Europe in the periods shown :

	Pre-War Period, 1936–38, %	After the end of the Marshall Plan, 1952–53, %
Circulating scrap	24	24
Factory scrap	11	12
Break-up scrap	15	16½
Imported scrap	2	0
Total	52	52½

A similar comparison for the U.S.A. in 1949, when the consumption of scrap in that country was estimated to be 54% of the melted material, indicated that circulating scrap amounted to 25½%, factory scrap to 22½%, and imported scrap to 6%. In Germany the average consumption of scrap was as follows :

Year	Average Consumption, %	Year	Average Consumption, %
1932	60	1935	50
1933	58	1936	50
1934	55	1937	50

It may therefore be assumed that the average amount of scrap available is about 50%.

Although the average consumption of scrap is about the same in Europe as in the U.S.A., there is a considerable difference in the way in which it is consumed by the various steelmaking processes in the two countries. American open-hearth works generally use 50–55% of scrap and 40–50% of pig iron ; in Europe, for the periods 1936–38 and 1952–53, the corresponding figures are estimated to be 57–60% of scrap and only 40–42% of pig iron, because the 36% of basic Bessemer steel produced allows the percentage of scrap used in open-hearth furnaces to be as high as 57%, while the average scrap consumption for the industry remains at 52%. With an increase in the amount of converter steel produced, the proportion of scrap in the open-hearth works can be raised, for a given quantity of scrap, which is equivalent to a reduction in the average ingot cost prices.

European steel production, according to the long-term programme, will rise from its present level of 49,000,000 tons to 59,000,000 tons in 1952–53. With this increased steel output, an additional production of 2,500,000 tons/year of circulating scrap may be anticipated. Since the increased production will be almost exclusively from open-hearth plants, and assuming that the proportion of scrap additions remains the same (57%), 2,500,000 tons of the 5,700,000 tons of additional scrap required should be immediately available. To contribute towards the remaining

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3,200,000 tons required, a further 1,000,000 tons of factory scrap may be anticipated within one year. It will not be possible, however, to make up the shortage of 2,200,000 tons for some time, so that the scrap additions in open-hearth furnaces will probably fall from 57% to 52%, involving an increase in ingot costs of about 3%, at present prices.

Table 1*a*

COSTS PER TON OF STEEL FOR AN OPEN-HEARTH PLANT, USING 50% SCRAP, 50% PIG IRON

Item	Approx. Price per ton of Material	Wt. of Material, kg./ton	Costs	
			At Scrap Price of £6/13/0 per ton	At Scrap Price of £3/6/0 per ton
	£ s. d.		£ s. d.	£ s. d.
Pig iron	10 0 0	510	5 2 0	5 2 0
Scrap	...	510	3 8 0	1 14 0
Ore	3 5 0	70	5 0	5 0
Alloys	66 13 4	5	6 8	6 8
Lime, etc.	4 0 0	(50)	4 0	4 0
Total raw materials		1095	9 5 8	7 11 8
Less scrap credit			1 8	1 8
Net raw-material costs			9 4 0	7 10 0
Refining costs			3 6 0	3 6 0
Ingot costs			12 10 0	10 16 0
Less slag credit			....	...
Net ingot costs			12 10 0	10 16 0

It may be of interest, from the economic viewpoint, to examine whether the production of open-hearth steel and of converter steel could not be increased in the same proportion, so avoiding difficulties in the provision of scrap ; the new strip mills and sheet-production methods, however, require essentially steel of open-hearth quality.

Process Costs

A comparison between the costs of the open-hearth and the basic converter processes is given in Table I. For simplicity, the costs of alloy and non-metallic additions are assumed to be the same in both processes. The average cost of raw materials for a works producing 30% of basic Bessemer steel and 70% of

Table I*c*

COSTS PER TON OF STEEL FOR A MIXED PLANT, PRODUCING TWO-THIRDS OPEN-HEARTH STEEL AND ONE-THIRD BESSEMER STEEL

Item	At Scrap Price of £6/13/0 per ton	At Scrap Price of £3/6/0 per ton
	£ s. d.	£ s. d.
Raw-material costs		
(*a*) Open-hearth production	5 15 6	4 0 8
(*b*) Basic Bessemer production	4 0 9	4 0 7
Total	9 16 3	8 1 3
Refining costs		
(*a*) Open-hearth production	2 4 0	2 4 0
(*b*) Basic Bessemer production	9 6	9 6
Total ingot costs*	12 9 9	10 14 9
Less slag credit	3 9	3 9
Net ingot costs	12 6 0	10 11 0

* The figures for ingot costs are also applicable to stahleisen

Table I*b*—ANALYSIS OF COSTS PER TON OF STEEL FOR A MIXED PLANT

Item	Open-Hearth Section, Using 70% Scrap, 30% Pig Iron				Basic Bessemer Section			
	Approx. Price per Ton of Material	Wt. of Material, kg./ton	Costs		Approx. Price per Ton of Material	Wt. of Material, kg./ton	Costs	
			At Scrap Price of £6/13/0 per ton	At Scrap Price of £3/6/0 per ton			At Scrap Price of £6/13/0 per ton	At Scrap Price of £3/6/0 per ton
	£ s. d.		£ s. d.	£ s. d.	£ s. d.		£ s. d.	£ s. d.
Pig iron	10 0 0	300	3 0 0	3 0 0	10 0 0	1145	11 12 6	11 12 6
Scrap	...	780	5 4 0	2 12 0	...	5	8	4
Ore	...	...	...	...	...	...	...	...
Alloys	66 13 4	5	6 8	6 8	66 13 4	5	6 8	6 8
Lime, etc.	4 0 0	(50)	4 0	4 0	4 0 0	(50)	4 0	4 0
Total raw materials		1085	8 14 8	6 2 8		1155	12 3 10	12 3 6
Less scrap credit			1 8	1 8			1 8	1 8
Net raw-material costs			8 13 0	6 1 0			12 2 2	12 1 10
Refining costs			3 6 0	3 6 0			1 8 6	1 8 6
Ingot costs			11 19 0	9 7 0			13 10 8	13 10 4
Less slag credit			...	...			11 8	11 8
Net ingot costs			11 19 0	9 7 0			12 19 0	12 18 8

open-hearth steel is about 3% higher than the corresponding figure for a works producing open-hearth steel only, although the open-hearth furnaces operate with only 30% of pig iron, instead of the 50% which would be more advantageous, as they could then practically dispense with ore. This difference results from the inferior yield in the converter process (87%), and it also applies in a comparison of costs where cheaper scrap is available.

Using the prices of scrap and pig given in Table I, the total ingot costs for a works producing one-third basic Bessemer steel and two-thirds open-hearth steel are less than those for an entirely open-hearth plant, using 50% of scrap, by about 4*s.*/ton, *i.e.*, about 2%, provided that the total amount of scrap used is the same in both cases.

The basic Bessemer process produces only ordinary commercial grades of steel. Assuming that about 30% of the demand is for such grades, it is apparent that in those countries where conditions are favourable for the manufacture of basic Bessemer steel, *e.g.*, France, Belgium, Germany, and Sweden, it is cheaper to use that process for about one-third of the production.

Repeated attempts have been made in recent years to blow low-phosphorus stahleisen, *i.e.*, high-manganese, low-phosphorus iron. The blowing of stahleisen in the converter (in which process there is no gain from the production of slag) has no economic advantage over the open-hearth process, when the latter is worked with 50% of scrap (*see* Table I (*c*)).

The following conclusions may be drawn : (*a*) The ingot costs for a basic Bessemer works are about equal to those for a modern open-hearth plant, working with 50% of pig iron, if the price of scrap is about two-thirds that of pig iron ; if the scrap price is lower, then the open-hearth works is more economic. (*b*) If scrap is in short supply, and the open-hearth furnaces have to work with charges containing a large amount of pig iron, it would be expedient to make commercial steels by the basic Bessemer process, should suitable raw materials be available. (*c*) If conditions are not suitable for the basic Bessemer process, the 30% converter steel production may be blown from stahleisen, although, in cost, there would probably be no advantage over open-hearth steel. (*d*) If an increase in steelmaking capacity for processes based on ore and pig iron is necessary, basic Bessemer converters should be installed to treat the pig iron, since, in spite of the high consumption of pig iron, the total amount of steel produced will be at the same cost per ton as before : an extension of open-hearth steel production, using pig iron as raw material, would result in an increase in the price of the steel. Analysis of the relationship between ingot costs and the monthly ingot-steel capacity in a German works in 1930 (*see* Fig. 1), shows that steelworks producing less than 400,000 tons/year of commercial-grade steel are no longer an economic proposition.

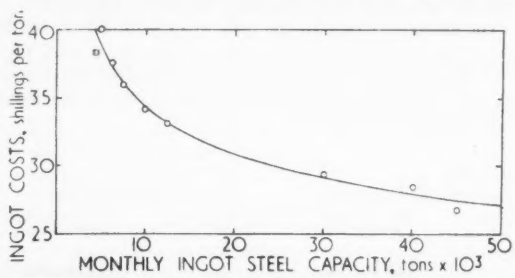


Fig. 1—Relationship of ingot costs to monthly ingot steel capacity for German steelworks (1930)

Heat Economy

In considering the blowing of ordinary stahleisen in the converter, attention must be paid to the heat economy. Using the classical values for the heat evolved by the combustion of carbon, silicon, manganese, phosphorus, and iron in the steel, the theoretical amounts of heat that would be liberated during the blowing of a stahleisen containing 4% of carbon, 0·7% of silicon, 2% of manganese, and 0·1% of phosphorus, are as follows :

Material Combusted	Rise in Temp., °C. Air	Oxygen
C, from 4–0·1%	24	100
Si, from 0·7–0%	133	161
Mn, from 2·2–0·4%	86	122
P, from 0·13–0·03%	12	18
Fe loss, 2%	56	94
Total	311	495

The corresponding calculation for basic Bessemer pig iron gives a rise in temperature of 518° C., and for acid Bessemer iron, 504° C. These figures apply to the limiting case, in which the gases evolved burn only to the first stage of oxidation ; in actual practice, this is only partially true. In tests made by the author, increases in temperature for stahleisen from 1250° to 1550° C. (uncorrected) were recorded.

It is clear that the heat equilibrium in the blowing of ordinary pig iron is very critical, and that only really hot stahleisen can be blown easily. There is no question of superheating, as in the case of basic Bessemer steel. It has been suggested—as early as 1856 by Bessemer—that oxygen-enriched air or oxygen should be used instead of air for blowing : the temperature values given above suggest that oxygen would be much more suitable. The theoretical rise in temperature when oxygen is used for blowing is of the same order as that obtained in the acid and basic Bessemer processes.

Professor Durrer has recently renewed the suggestion of using pure oxygen for blowing, and has pointed out that the temperatures thus obtained are so high that a considerable amount of scrap (25–30%) can be added. Also, owing to the small evolution of gas when blowing with oxygen, losses through ejects are less.

In experiments with oxygen, temperatures from 100° to 150° C. higher than with air were in fact obtained. Blowing with oxygen gave not only good heat economy and steadier working conditions, but also a better product. Oxygen-blown steel has a very low nitrogen content of about 0·005%.

Some years ago the author proposed to equip a converter with a coreless induction heater and so introduce by electrical means the necessary additional heat to the molten-metal bath during the blowing. The economic aspects of this method are discussed later.

ECONOMIC ASPECTS OF NEW PROCESSES

When oxygen is used a better yield may be anticipated, and a greater proportion of scrap (30%) may be employed in the charge. On the other hand, conversion costs are higher with oxygen than with air, and the wear on the converter is greater.

Tables I and II show that the ingot costs for oxygen-blown converter steel are 5% higher (*i.e.*, 16*s.* 8*d.* per ton) than those for an entirely open-hearth plant using 50% of pig iron, if the price of scrap is £6 13*s.* 0*d.* per ton. If the price of scrap is £3 6*s.* 0*d.* per ton the corresponding figures are 11% and £1 10*s.* 8*d.*

However, if an open-hearth plant operates with not more than 30% of scrap, a combined works turning out 30% of oxygen-blown steel and 70% of open-hearth steel has approximately the same ingot costs : those of the former are £12 11*s.* 0*d.* per ton, and those of the latter, £12 14*s.* 0*d.*

The blowing of steel with oxygen seems, therefore, to be a promising method ; it enables the converter to use scrap and, at the same time, to produce steel of quality equal to that of open-hearth steel, at a comparable cost. Also, for a converter plant, the capital outlay is less than for an open-hearth works of equal capacity, and the plant takes up less space and needs less time to build.

Induction Heating in the Converter

In order to make the heat economy for blowing ordinary stahleisen equal to that for blowing basic pig it is necessary to increase the temperature rise from 300° to 500° C. To supply this additional heat, electrical induction heating to provide 200 × 300 kg.cal., or approximately 70 kWh. per ton of steel is required (assuming that 1 kWh. = 860 kg.cal., and that 300 kg.cal. of heat are required to heat 1000 kg. of liquid steel through 1° C.).

The amount of heat required to melt scrap is 300 kg.cal./kg. Thus, for 30% of scrap, the amount of heat required is 300 × 310 kg.cal., or approximately 110 kWh./ton, and for 50% of scrap, the corresponding amounts are 500 × 310 kg.cal., or approximately 180 kWh./ton. Assuming the price of electricity to be 0·8*d.*/kWh., the refining costs are as follows :

	Refining Costs	
	30% of Scrap, cost/ton	50% of Scrap, cost/ton
Ordinary converter, without slag recovery	11*s.* 8*d.*	11*s.* 8*d.*
Heat supply to converter, 70 kWh. at 0·8*d.*/kWh.	4*s.* 8*d.*	4*s.* 8*d.*
Heat supply for melting scrap, 110 and 180 kWh. at 0·8*d.*/kWh.	7*s.* 4*d.*	12*s.* 0*d.*
Total	£1 3*s.* 8*d.*	£1 8*s.* 4*d.*

From Tables I, II, and III, and from similar calculations, the following comparison of the costs of the various processes may be made :

Ingot Costs per ton

	(*a*) Scrap price £6 13*s.* 0*d.*/ton		(*b*) Scrap price £3 6*s.* 0*d.*/ton	
	Pig Iron/Scrap Ratio : 1/1	Pig Iron/Scrap Ratio : 7/3	Pig Iron/Scrap Ratio : 1/1	Pig Iron/Scrap Ratio : 7/3
Open-hearth plant only	£12 10*s.* 0*d.*	...	£10 16*s.* 0*d.*	...
Converter using oxygen and stahleisen	...	£13 6*s.* 0*d.*	...	£12 6*s.* 8*d.*
Converter using induction heating and stahleisen	£12 10*s.* 0*d.*	£12 1*s.* 4*d.*	£10 13*s.* 0*d.*	£11 1*s.* 4*d.*
Basic Bessemer Converter (no scrap)	£12 19*s.* 0*d.*		£12 19*s.* 0*d.*	

Table II

COSTS PER TON OF STEEL FOR A BASIC CONVERTER USING OXYGEN

Item	Approx. Price per ton of Material	Wt. of Material, kg./ton	Costs	
			At Scrap Price of £6/13/0 per ton	At Scrap Price of £3/6/0 per ton
	£ s. d.		£ s. d.	£ s. d.
Pig iron	10 0 0	846	8 12 0	8 12 0
Scrap	...	288	2 0 0	1 0 0
Ore	...	...	...	...
Alloys	66 13 4	2·5	3 4	3 4
Lime, etc.	400 0 0	(50)	4 0	4 0
Total raw materials	...	1136·5	10 19 4	9 19 4
Less scrap credit	...		1 8	1 8
Net raw-material costs			10 17 8	9 17 8
Refining costs			2 9 0	2 9 0
Net ingot costs			13 6 8	12 6 8

It may be concluded that induction heating is a promising method for blowing stahleisen and those pig irons that are low in heat-generating elements, to produce commercial steels that are as cheap as basic Bessemer steel. Since ore can be added to the charge, a steel low in nitrogen and of open-hearth quality, can be produced at the same price as open-hearth steel and more cheaply than oxygen-blown steel. It is also possible, after blowing is finished, to carry out electric refining, to recarburize the steel, to add the alloy additions, and to finish the steel, in the same vessel. For this purpose, additional power is consumed at the rate of 50 kWh./ton, and electric steels and alloy steels can be produced in the usual electric-steel quality at an ingot cost of £12 10*s.* 0*d.* per ton, a price equal to that of open-hearth steel.

Alternatively, an ordinary slag-refining process without ore additions, can be carried out, so that the reaction of the remaining oxides with the residual carbon decreases the nitrogen content of the steel.

Induction heating in the converter makes it possible to carry out an electric-duplex process on a high pig-iron charge in the one vessel, thus avoiding the losses of heat and time involved in pouring the steel from one furnace into another.

The calculation in Table III was based on a charge of 0·8*d.*/kWh.; the usual price (0·2–0·3*d.*/kWh.) would, of course, make the results even more favourable.

Utilization of Manganese Content

When air was blown through stahleisen in an acid converter, it was found that, after only 4 min., the manganese content of 2–3% had fallen to as low as 1–1½%, while the carbon content remained essentially unchanged. The composition of the slag was 30–40% of SiO_2, 35–55% of MnO, 1–2% of CaO, and 6–16% of FeO, with a phosphorus content of only 0·01–0·03%; such a slag would be suitable for the manufacture of low-phosphorus grades of ferro-manganese. With a manganese content of 45% MnO (= 35% Mn), this slag can replace about 35–40% of low-manganese ore, and may be valued at £7 0*s.* 0*d.* per ton. For a manganese loss of 1½%, the slag yield is 3·3%, with a selling value of 4*s.* 6*d.* per ton.

After blowing for 4 min., the temperature of the steel had risen by 150° C. It may be assumed that in emptying out the melt so as to collect the high-manganese slag, and in pouring it back into the converter, most of this increase in temperature is lost.

The rise in temperature during the blow occurs as follows :

Material Combusted		Rise in Temp., °C. Air	Oxygen
C, from 4–0·1%		24	100
Mn, from 1–0·5%		23	32
P, from 0·1–0·03%		56	18
Fe loss, 2%		56	94
	Total	115	244

Table III

COSTS PER TON OF STEEL FOR A BASIC CONVERTER USING INDUCTION HEATING

Item	Approx. Price per Ton of Material	Wt. of Material, kg./ton	Costs: At Scrap Price of £6/13/0 per ton	Costs: At Scrap Price of £3/6/0 per ton
	£ s. d.		£ s. d.	£ s. d.
Pig iron	10 0 0	846	8 12 0	8 12 0
Scrap	...	288	2 0 0	1 0 0
Ore	...	...	...	...
Alloys	66 13 4	2·5	3 4	3 4
Lime, etc.	4 0 0	(50)	4 0	4 0
Total raw materials		1136·5	10 19 4	9 19 4
Less scrap credit			1 8	1 8
Net raw-material costs			10 17 8	9 17 8
Refining costs (less cost of electricity)			11 8	11 8
Cost of electricity			12 0	12 0
Net ingot costs			12 1 4	11 1 4

An additional increase in temperature of 150° C., to compensate for the heat lost in pouring, is necessary. This increase would correspond exactly to the heat consumed in melting 30% of scrap, so that in the oxygen converter the extra rise in temperature of 244° C. suffices to blow pig iron alone, without the addition of scrap. The supply of the additional heat would, however, lead to an increase in the charge and ingot costs of 18*s.* 3*d.* per ton, against which can be set only the value of the manganese slag, namely, 4*s.* 6*d.* per ton. The oxygen process would thus be more costly, by 13*s.* 9*d.* per ton. Conditions in the induction converter are as follows :

Power required to produce 150° C. temperature rise = 150 × 310 kg.cal., or 54 kWh./ton.
Additional costs = 54 × 0·8*d.*, *i.e.*, 3*s.* 6*d.* per ton.
Slag recovery profit = 4*s.* 6*d.* per ton.

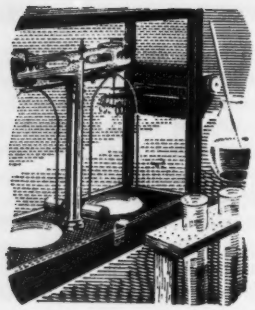
With the induction converter, therefore, there is a profit of 1*s.* 0*d.* per ton. Whether this profit is in fact realized must be shown in actual practice. It is certain, however, that separation of the manganese slag in an induction-heated converter, without additional cost, and with continuous recovery of manganese from the pig iron, can be done. The quantity of manganese so recovered amounts to 1½% × 80% = 12 kg. of manganese, or 15 kg. of ferro-manganese, per ton of ingot steel. Assuming that 6 kg. of manganese are required to make each ton of ingot steel, if one-third of a works' production consisted of induction-heated converter steel, and two-thirds of open-hearth steel, the ferro-manganese requirements of the works from outside sources would be reduced by two-thirds.

It would, of course, be possible to carry out only one preliminary blow in the converter, before pouring into the open-hearth furnace, and recover the same quantity of manganese. The temperature losses would then have to be compensated by heating in the open-hearth furnace. The economic aspects of working in this way would, however, have to be investigated in practice.

FILM ON GATING

Through the courtesy of the American Foundrymen's Society, the Research and Development Division of the British Steel Founders' Association has recently had the loan of an interesting film entitled "A Study of the Principles of Gating." The film records the results of a year's work conducted by the Battelle Memorial Institute, in which a technique employing transparent perspex moulds and water containing a suspension of fine aluminium powder, was used. By filming the flow of liquid in slow motion, the influence of runner, sprue, and ingate design and of pouring method upon both mould gas entrainment and turbulence of flow have been demonstrated in an interesting and convincing manner.

The film was shown by the Institute of British Foundrymen both at their Foundry Foremen's Training Course at Ashorne Hill on March 8th, and at a meeting of their technical sub-committee TS24 which met in Birmingham on March 19th.



B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Fuel Flow

WORKS TRIAL OF A METERING PUMP

By A. L. Cude, B.Sc., and J. Stringer, B.A.

SYNOPSIS

This paper describes the works trial of a metering pump installed on a 75-ton open-hearth furnace and operated for a total of approximately 400 hours. The pump gave much greater consistency of flow than normal hand-valve regulation, but this did not reduce the variability of the roof temperature. This variation is considered to be due to the dominating effect of manual control of the roof temperature.

It is shown that the metering pump would offer a number of advantages over the conventional motorized valve, as a component of an automatic temperature controller. This application probably represents the most favourable direction for further development.

The pump itself appeared to have suffered no undue wear as a result of pumping heavy fuel oil, but the stall-valve, employed to return the pump to zero setting automatically during reversal, was adversely affected by the accumulation of dirt. A method of eliminating the stall-valve is suggested.

An electronic motor-speed control was used in these tests, and the possibility of replacing this by a simpler arrangement to compensate for speed variation is discussed. Speed compensation would be unnecessary if the pump were used as part of an automatic temperature controller.

THE possibility of using a metering pump to obtain more consistent control of the input of heavy fuel oil to the open-hearth and other steelworks furnaces has been discussed by Stringer and Gay.* They described the results of laboratory tests of a number of pumps, and concluded with proposals for a works trial of one of these. The purpose of this report is to describe the observations made during this trial at the works of the Shelton Iron, Steel and Coal Co., Ltd., and to indicate the possible future development of the pump.

EXPERIMENTAL INSTALLATION

Pump

The pump† employed was a commercial model of Pump *B* described by Stringer and Gay. The essential features are shown in Fig. 1. It had seven pistons reciprocating in a rotating cylinder block, one end of which ran against a machined face containing inlet and outlet ports. The outer ends of the pistons were spring-loaded to bear against a cam-plate pivoted about one diameter. The inclination of the cam-plate was varied manually over a range of about 15°, thereby varying the stroke and hence the pump delivery. The pump included a stall-valve, which was a simple form of automatic servo mechanism, by which the cam-plate was returned to the zero position whenever the pump delivery pressure exceeded a preset maximum.

Drive

Because the pump delivery was a function of the pump speed as well as of the cam-plate setting, it was necessary to maintain the speed constant within narrow limits. To do this the pump was driven by a 3-h.p. motor under the control of an electronic speed controller designed to keep the speed constant to within 0·5% of 1340 r.p.m. at all loads. Since the pump was designed to run at 2000 r.p.m., a 3 : 2 step-up chain drive running in an oil bath was used.

Installation

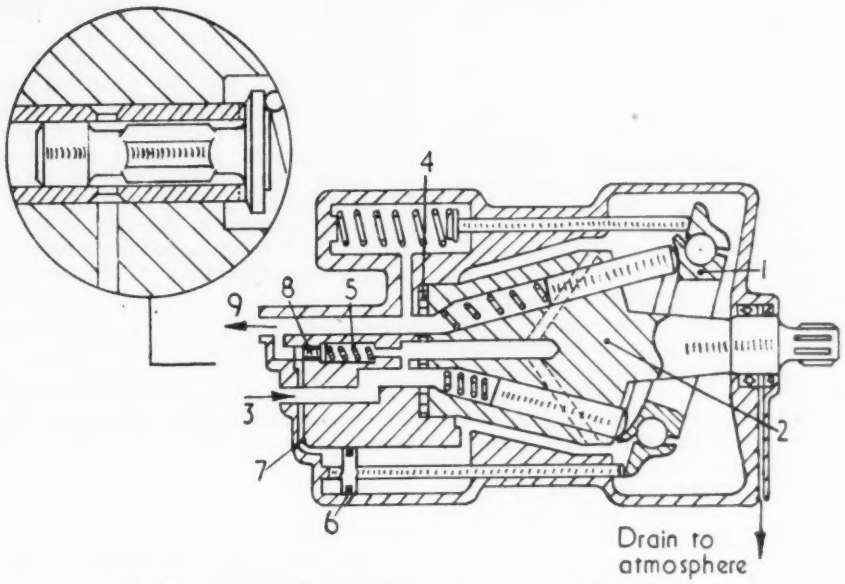
The general arrangement of the oil flow system is shown in Fig. 2. Oil circulated through a ring main at a pressure of 140 lb./sq. in. on the incoming side.

Paper PE/AB/29/50 of the Instrument Sub-Committee of the Fuel Committee of the British Iron and Steel Research Association (Plant Engineering Division), received 17th October, 1950. The views expressed are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

Mr. Cude is on the staff of the Plant Engineering Division of the British Iron and Steel Research Association. Mr. Stringer is with London Transport Executive, and was formerly in the Plant Engineering Division of the Association.

* J. Stringer and A. F. Gray, *Journal of The Iron and Steel Institute*, 1949, vol. 163, pp. 71–80.

† Manufactured by Messrs. Joseph Lucas (Gas Turbine Equipment), Ltd.



1. Cam-plate
2. Rotor
3. Pump inlet
4. Insert
5. Spring (for shuttle valve)
6. Servo piston
7. Drilling
8. Shuttle-type relief valve
9. Pump inlet

Fig. 1—Diagram of the Lucas pump. (*Reproduced by courtesy of Joseph Lucas (Gas Turbine Equipment), Ltd.*)

The oil supply to the furnace passed through an orifice meter and was then directed to the required end of the furnace by plug-type reversing valves 5 and 6. Control was effected by the valves 4 and 7. The pump, with its ancillary apparatus, was contained in a separate loop connected across the by-pass valve 3 and provided with isolating valves 1 and 2. It could thus be operated by means of these three valves, without disturbing the furnace. The orifice meter continued to operate while the pump was working.

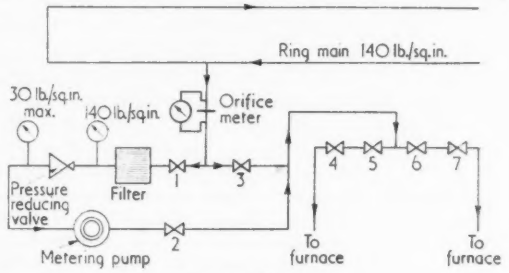
An edge-type filter with plate spacings of 0·005 in. was provided, to reduce the risk of damage to the pump by solid matter in the oil. Since the pump was not designed to withstand an inlet oil pressure greater than 30 lb./sq. in., it was also necessary to provide a pressure-reducing valve, to protect the pump from the full ring-main pressure. Because of the limited space available, the pump and other equipment were mounted on a platform below the furnace stage level, as shown in Fig. 3. The cabinet housing the electronic speed control was placed in a protected part of the stage.

Adjustment of the cam-plate was effected by a handwheel on the furnace control panel, through a wire rope drive. There proved to be too much stretch and slip in this system for the handwheel to provide a direct indication of the cam-plate setting. Accordingly, one of the cam-plate mountings was extended through the pump casing, its position being transmitted electrically to an indicator on the control panel by means of a ' Desynn ' position transmitter.* The indicator was calibrated to correspond with the orifice flow indicator, so that the operators could continue to work to familiar readings.

Details of Furnace

The furnace was a 75-ton basic open-hearth furnace, charging approximately 50 tons of scrap and 25 tons of hot metal. Instruments included the following :

* Manufactured by Messrs. Smith's Industrial Instruments, Ltd.



1, 2. Pump isolating valves
3. Pump by-pass valve
4, 7. Flow control valves
5, 6. Reversing valves

Fig. 2—Flow diagram of metering pump installation

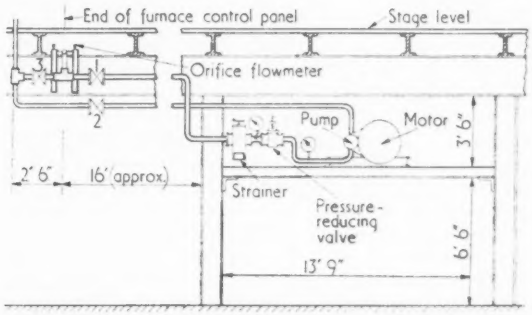


Fig. 3—Elevation of metering pump installation

Recorders for—Roof temperature; oil flow; atomizing steam flow; air flow; furnace pressure; draught.
Indicators for—Oil pressure; oil temperature; atomizing steam pressure.

The oil flow was regulated, up to a maximum of 320 gal./hr., to maintain the roof temperature as close as possible to the permitted maximum of 1640° C.* Reversing was carried out every 10 minutes, and occupied approximately 15 seconds.

OPERATION OF PUMP

To start the pump, the motor was started and the isolating valves 1 and 2 (Fig. 2) were opened. The stall-valve was set to operate at a pressure slightly higher than that of the ring main, so that the pump now started to pump oil, but without affecting the furnace as the by-pass valve 3 remained open. Cold oil in the pump loop did not cause any trouble. When oil had circulated for a few minutes to warm the pump and filter, the pump was set to the flow rate required by the furnace, and the by-pass valve was closed. The pump took over control of the flow at once, without any disturbance of the flame. Control valves 4 and 7 were then opened completely, as they served no useful purpose with the pump running.

Reversing was effected in the normal way by operation of the reversing valves 5 and 6. During the period when the oil flow was interrupted, the stall-valve automatically returned the cam-plate to its zero position.

During the fettling period, the oil was shut off at the reversing valves and the pump was allowed to run stalled.

OBSERVATIONS DURING TRIAL

The pump was operated for a total time of approximately 400 hours. The first period of 100 hours was subject to frequent interruptions for adjustment and modification to the installation, particularly on the electrical side, but the final 300 hours were continuous. The run was concluded when it became apparent that the stall-valve was not working correctly.

Measurement of the electrical power absorbed by the motor armature indicated that the power required to drive the pump under various conditions was as follows :

Starting with cold oil	1·7 h.p.
Pumping oil (100° C., approx.) at 320 gal./hr. against a pressure differential of 110 lb./sq. in.	1·5 h.p.
Running stalled	1·0 h.p.

Control

Typical flowmeter charts, obtained with valve control and pump control respectively, are reproduced in Figs. 4*a* and *b*. The chart for valve control is characterized by its irregularity, varying over a mean range of $\pm 5\%$ of the mean flow during the charging period, when the input is nominally constant. The pump chart, on the other hand, shows great steadiness and complete freedom from unwanted flow changes.

To determine whether the improved consistency of flow control had any effect on the roof temperature, two groups of four casts were taken, one group with normal flow control and the other with the pump in operation. The charts were divided into arbitrary sections, each representing a 15-min. period, and the mean range, *i.e.*, the mean difference between maximum and minimum values for all sections, was determined. Only the latter part of each cast, when the temperature was nominally constant at its maximum value, was taken. The periods were arranged to cover the three shifts approximately equally, to allow for variation in the skill of the operators in making the frequent adjustments necessary to maintain a constant temperature. The results obtained were :

	Normal Control	Pump Control
No. of 15-min. periods	78	69
Mean temperature, ° C.	1652	1656
Mean range, ° C.	21·3	28·0

Statistical tests* showed that the difference between the mean ranges was just significant. There was one chance in twenty that it occurred by accident.

Pump Faults

(i) On one occasion all the pistons stuck in the conical cylinder ends. This was apparently caused by an excessively long maximum stroke, and was remedied accordingly.

(ii) On two occasions only, the pump failed to recover immediately after the flow had been reduced to zero.

(iii) The stall-valve sometimes behaved erratically, and the cam-plate did not always return to zero on reversal. On these occasions there was a marked rise in pressure on the inlet side, and it was concluded that the cylinder block had separated from the valve face sufficiently to allow backflow. There was no evidence of any loss of metering accuracy when oil was flowing.

(iv) The pump seals, made of synthetic rubber, were not satisfactory when used in contact with oil at approximately 100° C.

Condition of Pump at End of Trial

At the conclusion of the run the pump was returned to the makers and was stripped. It was found to be in good condition, and showed no measurable wear. There was a quantity of dirt in the stall-valve, including a gritty powder, which was probably rust picked up by the fuel oil, and a fibrous material, which probably came from the asbestos gaskets with which the synthetic rubber seals originally supplied had been replaced.

DISCUSSION

Consistency of Flow

Comparison of the two flow charts (Figs. 4*a* and *b*) shows that the pump gave greatly improved consistency of oil flow. With hand-valve regulation, the flow was continually varying over a range of $\pm 5\%$. Part of this variation was due to overshooting when an adjustment was made. There was little correlation between valve movement and change of oil flow, because so many variables were involved, and the flowmeter indication lagged several seconds behind the

* Optical, corresponding to 1660° C. on radiation pyrometer.

* K. A. Brownlee, "Industrial Experimentation" (4th Ed.), pp. 36–60. London, 1948 : H.M. Stationery Office.

actual change of flow. Consequently, a small flow adjustment was a laborious affair of trial and error. With the pump the flow was determined by the cam-plate position, and the cam-plate was directly connected to the operating handle and the flow indicator, so that an adjustment could be made at once without hunting.

Once set, the flow remained constant until the next adjustment. This was appreciated by the melters, who claimed that the pump made their work easier, particularly during charging, when they were not free to make frequent adjustments to the oil flow.

Roof Temperature

The improved regulation of the oil flow did not appear to improve the control of the roof temperature, which showed a variation of $\pm$ 14° C., compared with $\pm$ 10·7° C. for hand-valve regulation. This probably arose because the operators had had little experience in handling the pump.

Whilst the use of a flow controller may not lead to much improvement if the ultimate control of the roof temperature is manual, the pump would be suitable for incorporation in an automatic temperature controller, when much closer control should be obtained (*see* p. 50).

Effect of Sediment in the Fuel Oil

Fuel oil is likely to contain a small amount of fine sedimentary matter, and it may also contain colloidal particles, which can agglomerate and block openings much larger than the individual particle diameter. Thus, any attempt at fine filtration will be difficult. The cheapest grades of fuel oil, which are the only ones that can be considered for steelworks use, contain the largest proportion of material likely to cause blockages, and it is probable that finer filtration than that at present employed would lead to difficulty. The present standard of cleanliness is adequate for the burners used, and it follows that the other components

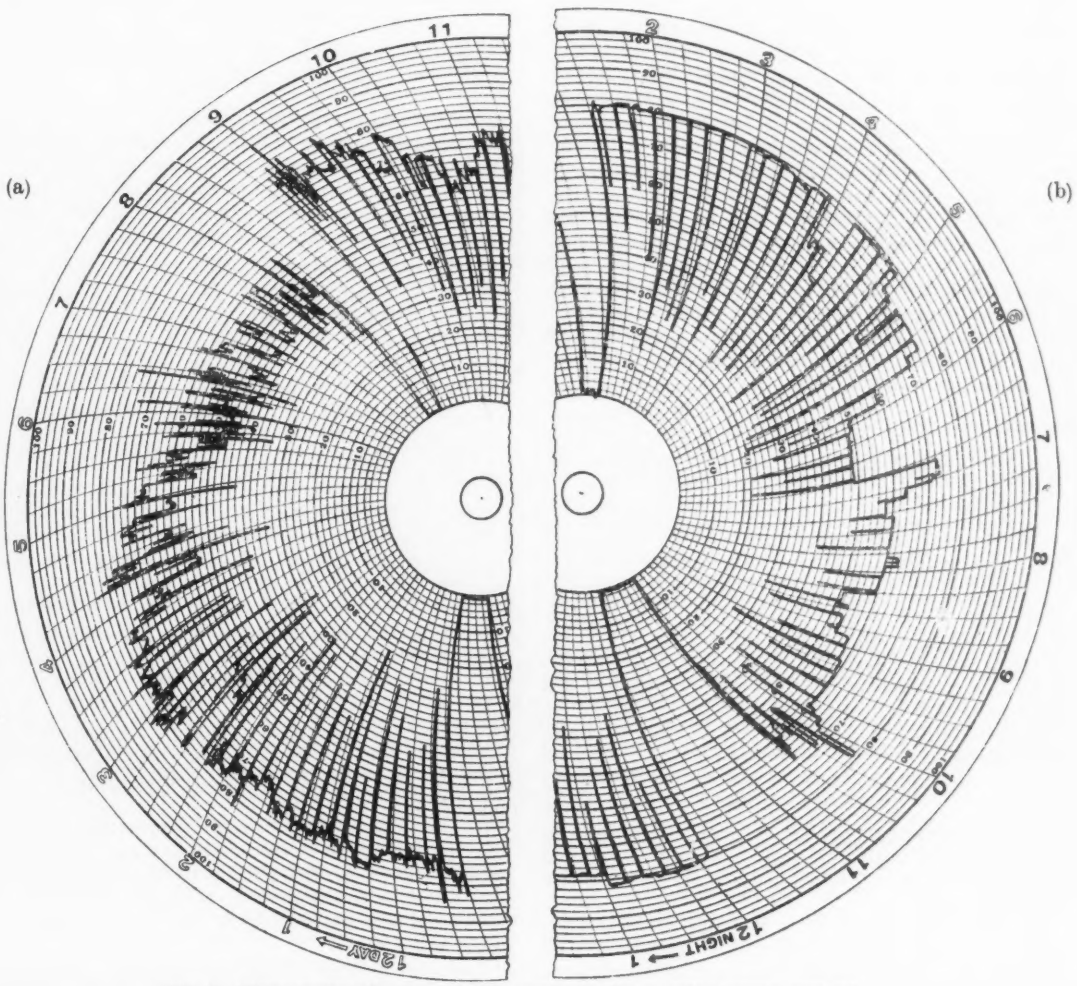


Fig. 4—Flow-meter charts: (*a*) valve control; (*b*) metering pump control

of the installation should not demand a higher degree of filtration.

There was no evidence that sediment in the oil caused any difficulty in the pump itself, the troubles experienced apparently being caused by dirt in the ancillary stall-valve. It was necessary to use the stall-valve so as to employ the existing reversing arrangements without modification, but it would be possible to link the reversing gear to the cam-plate, to bring it directly to zero. With the addition of an emergency relief valve to deal with accidents, the stall-valve could then be dispensed with entirely.

Sealing Materials

The synthetic rubber seals originally supplied did not prove satisfactory, and it will be necessary to find a material better able to resist oil at temperatures of about 100° C.

Speed Control

In the form tested, the pump needed an electronic speed control mechanism. Alternatively, the pump could be driven by a normal 3-phase motor, with corrections for speed variations applied to the pump cam-plate. This method is discussed in detail in the Appendix, and it is shown that this approach to the problem would probably result in a simpler and cheaper mechanism.

If the pump formed part of an automatic temperature controller, speed control could be eliminated. A 3-phase motor would vary in speed by only a small amount over a short period, and the effect of this would be compensated by its reaction on the furnace temperature.

Adopting either method, it would still be possible to use the pump to indicate rate of flow and total flow, but the indicating mechanism would need to be adapted to take into account the pump speed, as well as the cam-plate setting.

Automatic Temperature Control

Compared with a normal motorized valve, the metering pump has the following advantages :

(i) A linear relation exists between input signal and flow response over the full working range
(ii) Changes in oil viscosity have no effect
(iii) Changes in the oil pressure, whether on the suction or delivery side, have no effect
(iv) It is not necessary for the oil supply pressure to be always greater than the maximum pressure demanded by the burner.

A controller incorporating the pump would, therefore, offer real advantages to the designer of the apparatus, and would be particularly useful in an extensive distribution system, where large pressure fluctuations are most likely to occur.

CONCLUSIONS

(1) The metering pump confirmed the promise of the laboratory work, and gave a greatly improved consistency of flow compared with the hand valve normally used.

(2) The pump has a linear response characteristic, and is not affected by pressure changes in the oil distribution system. It is therefore particularly suitable for inclusion in an automatic temperature controller. This probably represents the best direction for future application of the pump.

(3) Correction for speed variation by adjustment of the pump cam-plate should result in a simpler and cheaper apparatus than that used to control the speed of the motor. Speed control would be unnecessary if the pump formed part of a temperature controller.

(4) In whatever form it is applied, the pump can be arranged to indicate rate of flow and integrated total flow.

(5) Although the pump itself is satisfactory, the ancillaries require further development.

Acknowledgments

The authors thank Messrs. Joseph Lucas (Gas Turbine Equipment), Ltd., for the loan of the pump and for their co-operation in carrying out the trials. Their thanks are also due to the Shelton Iron, Coal and Steel Company, Ltd., who provided facilities for the trial and gave every possible assistance in the work.

APPENDIX

Compensation for Speed Variation in Metering Pumps

The discharge from a variable-displacement pump depends on the speed as well as on the pump displacement. In the experimental installation the speed was held constant within narrow limits, but alternatively the motor speed could be allowed to vary freely, and compensation applied to the pump displacement.

Theory of Speed Compensation

The characteristic equation of a variable-displacement metering pump has the form:

$$V = kaS \qquad (1)$$

where

V = volumetric discharge rate
k = pump calibration coefficient (substantially constant under normal working conditions)
a = angular setting of cam-plate or equivalent mechanism
S = pump speed.

The form of this equation shows that the constancy of the discharge rate for a given value of a depends on the constancy of the product aS. Therefore, if S is variable and the variations are measured by suitable means, a correction can be applied to a to maintain the product at the required value.

Differentiating equation (1) gives:

$$\frac{dV}{V} = \frac{da}{a} + \frac{dS}{S} \qquad (2)$$

The terms in equation (2) represent the proportional deviations of the variables from their nominal values. For zero error in the pump discharge, $dV/V = 0$, and $da/a = -ds/S$.

The term da/a represents the proportional adjustment to the nominal cam-plate setting, so that it would be necessary to include in the compensating mechanism a variable ratio device, connected to the pump setting control, to allow for variations in the value of a.

A simpler method would be to use a linear relation between S and a, without compensation for changes

in a. In this case, complete speed compensation would be obtained at only one pump setting, and the error would increase in proportion to the deviation from this setting. This simpler arrangement might be satisfactory in an application where the normal working range is narrow.

Accuracy of Measurement of Speed Deviation

To avoid excessively large corrections, which for mechanical reasons it may not be possible to apply, it is desirable to use a motor which is inherently fairly stable in speed. An ordinary 3-phase induction motor should be satisfactory, as the normal speed variations of these machines lie between + 3% and − 10% of the nominal speed. If the nominal speed is 1450 r.p.m., then the working range of the speed-sensitive device is 189 r.p.m., between 1305 r.p.m. and 1494 r.p.m.

It was shown on p. 50 that, for zero error in the pump discharge, da/a must be numerically equal to dS/S. If the two terms are not equal, their difference represents the relative error of the pump discharge. For most furnaces the limits of error can probably be put at $\pm 1\%$, so that the error equation can be written :

$$\frac{da}{a} = \frac{dS}{S} \pm 0{\cdot}01$$

In terms of actual speeds, and taking the lowest speed so as to give the smallest limits of permissible error, the speed-sensitive device must measure speeds over a range of 189 r.p.m. within $\pm$ 13 r.p.m.

In comparison, a speed control must, for the same accuracy, keep the speed within $1450 \pm 14{\cdot}5$ r.p.m. The maximum working range would then be only 29 r.p.m., and the controller would have to change the power input to the motor from ' no load ' to ' full load ' within this range. To do this smoothly, without hunting, the controller must be sensitive to a small fraction of the total range, probably to less than one r.p.m. It is evident that, for the same metering accuracy, the speed compensator needs to be much less sensitive than the speed controller, so that it may be simpler to design and cheaper to manufacture.

Type of Speed-Sensitive Device

Since the speed range is large and it is not necessary to detect very small differences in speed, it should be possible to make use of one of the following devices :

(i) A mechanical centrifugal governor
(ii) A hydraulic governor, in which the pressure developed by rotation of a body of fluid is used as the operating signal.

Both would require a simple form of hydraulic servo motor incorporating some form of compensation for the inherent square law characteristic of both forms of primary device. The necessary power for this could be obtained from a small gear pump.

Speed Compensation *versus* Speed Control

(1) For a given degree of metering accuracy, speed compensation requires a much lower sensitivity to small variations in speed.

(2) The speed compensator has to handle only the low power necessary to adjust the pump cam-plate, whereas the speed controller has to handle all the power to the motor.

(3) If the pump cam-plate setting is obtained by some form of servo mechanism (for example, as part of an automatic control) then the speed compensator can be combined with this apparatus with the minimum of extra mechanism. A speed controller would be completely separate.

(4) From the above considerations, speed compensation should prove much less costly, in both capital and maintenance charges, than speed control.

Determination of Tin in Ferro-Tungsten and Tungsten Metal

By the Methods of Analysis Committee

SYNOPSIS

Two methods are described for the determination of tin in ferro-tungsten and tungsten metal powder.

In both, the preliminary decomposition is carried out by attack with mixed acids, including hydrofluoric acid. In the first method tungstic acid is complexed with citric acid before precipitation of the tin as sulphide, a separation procedure previously employed for alloy steels, while the second method utilizes a hydrolytic precipitation and separation of the tungsten; absorption losses of tin in the precipitate are discussed and shown to be of minor importance. In each case the procedure is completed in accordance with the B.S.I. method for tin in steels.

Various alternative methods of decomposition have been examined and data and results showing the comparative performance of the two methods are given.

Introduction

During recent years chemists have received, with increasing frequency, demands for accurate determinations of the tin content of various classes of steel. In particular, tungsten steels have assumed special significance in this direction because of the common association of tin and tungsten minerals, with the result that some grades of ferro-tungsten may introduce undesirable amounts of tin into the steel.

Methods have already been published[1, 2, 3] covering

Paper MG/DC/234/50 of the Highly Alloyed Steels and Ferro-Alloys Sub-Committee of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 11th October, 1950.

Table I

SODIUM PEROXIDE FUSION PROCEDURE

Operator	1	2	3	4	5	6	7	8
Tin in Ferro-tungsten, % (Sample MGS/99)	0·125 0·125	0·124 0·122 0·124	0·104 0·108	0·119 0·115	0·12 0·14	0·126 0·131	0·135 0·138	0·124 0·125

the determination of tin in all classes of steels. The present report is the result of a further study of these methods and refers specifically to the problem as applied to ferro-tungsten alloys. It is recognized that other ferro-alloys likely to contain tin, *e.g.*, ferro-niobium, may equally merit consideration and the Sub-Committee responsible for the work has kept in mind the need for utilizing principles which are potentially capable of being extended to a more comprehensive range of ferro-alloys.

The investigation has been conducted by the Highly Alloyed Steels and Ferro-Alloys Analysis Sub-Committee (a Sub-Committee of the Methods of Analysis Committee), constituted as follows:

Mr. B. BAGSHAWE (*Chairman*)	Brown-Firth Research Laboratories
Dr. J. CAMERON	Clyde Alloy Steel Co., Ltd.
Mr. E. DYKE	Brown-Firth Research Laboratories
Mr. W. T. ELWELL	I.C.I., Ltd., Billingham Division
Mr. L. E. GARDNER	Edgar Allen and Co., Ltd.
Mr. C. L. GRAYSON	English Steel Corporation, Ltd.
Mr. E. W. HARPHAM	B.S.A. Group Research Centre
Mr. S. HARRISON	Kayser, Ellison and Co., Ltd.
Mr. J. D. HILL	Bragg Laboratory, N.O.I.D.
Mr. R. T. POSTLETHWAITE	Samuel Fox and Co., Ltd.
Mr. J. L. WEST	Hadfields, Ltd.

In adapting an established principle for the determination of tin in steels to its determination in ferro-tungsten, the simple expedient of removing tungsten as unattacked carbide or tungstide cannot be utilized owing to essential differences in the method of decomposition that must be adopted. Alternative provision must, therefore, be made, either by conversion of the tungsten to a non-interfering complex or by its removal, since in the materials considered tungsten may be present to the extent of 80% or more.

METHODS OF DECOMPOSITION

The various methods of decomposition which have been considered may be broadly classified as (*a*) fusion with acid and alkaline fluxes, and (*b*) decomposition by acid mixtures containing hydrofluoric acid. The most rapid decomposition is effected by fusion with sodium peroxide in an iron or nickel crucible. Preliminary trials were made by fusing an intimate mixture of 2 g. of the finely powdered alloy and 10 g. of sodium peroxide with a covering layer of 2 g. of sodium carbonate. In all cases decomposition was rapid and complete. The fusion extracts were treated with citric acid to fix tungstic acid in stable solution, and after suitable adjustment of the acidity the sulphide separation method was applied exactly as developed for steels. The results on a ferro-tungsten test sample (Table I) were distinctly promising, but corrections were necessary for tin introduced from the metal crucible.

These corrections are not easily applied because the tin content of the crucible metal must be known. Also, the amount introduced depends on the condition of the crucible and on the time and intensity of individual fusions. In three tests, using iron crucibles, the results given in Table II were obtained.

In view of this, sodium peroxide fusion was abandoned, as it was considered that although the substitution of nickel for iron crucibles would reduce the effect, the introduction of substantial concentrations of nickel salts was an undesirable complication.

Acid fusion agents, comprising potassium bisulphate, potassium nitrate, and a mixture of ammonium sulphate and ammonium bifluoride, were tested on a limited scale. In the case of bisulphate it is necessary to submit the metal powder to a prolonged roasting to oxide (about 3 hr.) before fusion. Apart from this the decomposition was satisfactory and leaching of the fusion products in an acid citrate medium gave a solution to which the established steel procedure could be applied. Fusion with ammonium sulphate and bifluoride overcame the need for the preliminary roasting, but it was necessary to complete the operation by fusing the decomposition products with potassium bisulphate.

The most satisfactory results were obtained by wet decomposition in platinum vessels by mineral acid mixtures, of which hydrofluoric acid was the primary component. Attack by hydrofluoric acid, alone or in admixture with sulphuric acid, is slow, but when nitric acid is introduced rapid, and sometimes vigorous, decomposition results. The reaction can be controlled by using a covered crucible and introducing the nitric acid dropwise until vigorous action ceases. A mixture containing 5 ml. of sulphuric acid (1 : 1) and 5 ml. of hydrofluoric acid completely decomposed 2 g. of ferro-tungsten when nitric acid was added and was quieter in action than hydrofluoric acid alone. In all cases this type of decomposition

Table II

EFFECT OF ATTACK ON CRUCIBLES IN FUSION PROCEDURE

Tin in Crucible, %	Loss of Weight Single Fusion, g.	Tin Introduced into Determination, %
0·03	2·2	0·033
0·012	1·78	0·011
0·012	1·56	0·009

Table III

Test	Standing Time	Tungsten in Filtrate, % Direct	Tungsten in Filtrate, % $Fe(OH)_3$ Precipitation
1	1 hr.	0·085	0·085
2	3 hr.	0·12	0·12
3	Overnight	0·06	0·06

must be followed by sulphuric acid fuming to expel nitric and hydrofluoric acids; this is best effected under a radiant heater. Such treatment yields a dense tungstic acid residue, which is only slightly soluble in dilute mineral acid. This decomposition procedure, therefore, provides two alternatives by which the determination may be completed:

(1) Extraction with citrate to 'fix' tungstic acid in solution, followed by the sulphide separation method as developed for steels

(2) Separation of the tungstic acid from a mineral acid extract followed by direct reduction and titration of tin.

COMPARISON OF TUNGSTEN REMOVAL AND SULPHIDE SEPARATION PROCEDURES

The advantages of a direct tungsten separation, Method I (described in the Appendix), in terms of general simplification, are obvious if it can be shown that:

(*a*) The small amount of tungstic acid remaining in solution does not affect the reduction and titration of tin

(*b*) The separated tungstic acid does not occlude a significant amount of tin.

Residual Tungsten

Using the mixed acid procedure (*see* Appendix) 2-g. samples of ferro-tungsten, MGS/117, were decomposed and the fumed concentrates extracted in 100 ml. of hydrochloric acid (1 : 3). After varying periods of settling the tungstic oxide was removed by filtration and the tungsten remaining in the filtrate was determined on a quarter aliquot by the dithiol absorptiometric procedure.[4] The remainder of the filtrate was made ammoniacal and the precipitated ferric hydroxide was tested for tungsten in the same manner. The results are given in Table III.

These results show the efficiency of the removal of tungstic acid from dilute hydrochloric acid (1 : 3) extracts following fuming of the mixed acid decomposition solution. It is considered that dehydration at the mixed acid fuming stage favours maximum insolubility in hydrochloric acid because of the physical condition of the tungstic acid precipitate.

Table IV

Test	Tungsten Added (Equivalent on 2-g. Sample), %	Titration, ml. of N/100KIO$_3$	Remarks
1	0·2	0·15	No colour interference
2	0·4	0·15	,, ,, ,,
3	0·6	0·20	,, ,, ,,
4	1·0	0·15	Blue colour present, end-point not easily detected

This relatively high acidity is also more favourable for minimizing loss of stannic oxide by adsorption. The results show that soluble tungsten is quantitatively co-precipitated with ferric hydroxide and will, consequently, be present during the final reduction and titration of the tin.

Further tests were, therefore, carried out to assess the effect of residual tungsten on the tin determination. Tin-free solutions containing the equivalent of 0·4 g. of ferric iron, together with known additions of tungsten as sodium tungstate, were reduced and were titrated by the standard procedure; the results are shown in Table IV.

The titration values obtained are the same as the average blank titration given by the method and they show no evidence of significant interference from tungsten. At the 1% tungsten level the end-point becomes somewhat obscure, but this amount of residual tungsten is far in excess of that likely to be encountered in practice (*see* Table III). It is concluded, therefore, that the amount of tungsten left in solution, using this procedure, does not influence the tin determination.

Occluded Tin

Tests using Method II (described in the Appendix) were made on a series of three ferro-tungsten samples representing low, medium, and high tin grades and on one sample of tungsten metal powder, in which, in addition to the normal determination, the tungstic acid precipitates were separately examined for occluded tin. The accurate measurement of small amounts of tin is a matter of some difficulty and, to increase the significance of the results, it was necessary to combine the tungsten precipitates from

Table V

AMOUNT OF TIN IN WO_3 RESIDUE

Operator	Tin,* %															
	Method II								Method II*a*							
	MGS/99		MGS/117		MGS/118		MGS/119		MGS/99		MGS/117		MGS/118		MGS/119	
	Solution	Residue	Solution	Residue	Solution	Residue	Solution	Residue	Solution	Residue	Solution	Residue	Solution	Residue	Solution	Residue
1	0·122	0·0023	0·058	..	0·590	0·018	0·010	..	0·125	0·0018	0·055	0·0008	..	..	0·010	0·005
2	0·123	..	0·056	0·004	0·592	0·020	..	..	0·123	n.d.	0·052	0·005	0·577	0·023	..	..
3	0·125	trace	0·055	trace	0·602	0·007	0·009	nil	0·125	n.d.	0·054	trace	0·598	0·006	0·009	nil
4	0·112	trace	0·056	0·0017	..	..	0·006	trace	0·122	trace	0·057	0·0009	..	..	0·010	trace
5	0·132	0·003	0·058	0·002	0·591	0·007	0·009	nil	0·123	0·004	0·056	0·0025	..	..	0·008	0·001
6	0·112	0·005	0·055	0·003	0·599	0·014	0·008	0·001	0·110	0·008	0·052	nil	0·580	0·022	0·009	0·0006
7	0·096	n.d.	0·052	n.d.	..	..	0·015	..	0·120	n.d.	0·057	n.d.	..	..	0·015	..
8	0·124	0·0009	0·056	0·0011	0·590	0·020	0·009	nil	0·129	0·0005	0·057	0·0007	0·584	0·014	0·010	nil
9	..	..	..	..	0·60	trace	..	..	..	..	..	..	0·60	trace	..	..

* Average value obtained by each operator (*see* Table VI)
n.d. = not determined

two or three separate 2-g. determinations. The tungstic acid residues were examined for occluded tin in accordance with the conditions outlined in an earlier paper[3] (p. 191). The results are given in Table V (Method II). The presence of small amounts of occluded tin in the tungstic acid is confirmed, but the amount involved is very small and does not significantly affect the results when compared with those for Method I (*see* Table VI).

The results for Method II*a* (Table V) give further evidence that minor amounts of tin are associated with the tungsten residue. This method employs a similar tungstic acid separation to Method II and the determination is completed by precipitation of the tin as sulphide as in Method I, but the inclusion of this refinement is unnecessary, since equally satisfactory results are obtained in Method II without the use of hydrogen sulphide. The loss of tin in the tungsten residue varies from a trace to a maximum of 0·008% at a tin content of 0·12%, with an average loss of $<0·003\%$. At 0·6% of tin the residue recovery is rather higher, as would be expected, and in several instances exceeds the equivalent of 0·01%. Even so, the results by Method II show excellent agreement with those by Method I; at the 0·6% tin level only the second decimal place should be regarded as significant. The mean value by Method II, without residue recovery, is 0·595% of tin against 0·60% of tin by Method I.

It is not easy to incorporate a residue recovery treatment in Method II without losing the essential simplicity of the method, but a note has been added which provides for an ammoniacal extraction of the filtered tungstic acid precipitate. The tin, co-precipitated with a small amount of ferric hydroxide, is then returned to the main solution. Results of 0·61, 0·62, and 0·62% of tin have been obtained in this way on the high-tin ferro-alloy MGS/118.

RESULTS AND CONCLUSIONS

The complete record of results on the samples of ferro-tungsten and tungsten metal powder, shown in Tables V and VI, confirms the adequacy of the proposed methods.

Method I holds an advantage in principle since no evidence exists for loss of tin at any stage of the process. Method II is simple, requires very much less time for its operation, and has definite advantages for routine work. There is evidence in support of a minor adsorption of tin in the tungstic acid precipitate, but the error involved does not significantly affect the practical value of the method or its concordance with Method I; a note incorporating an

Table VI

DETERMINATION OF TIN IN FERRO-TUNGSTEN

Operator	Tin, %											
	Method I				Method II				Method II*a*			
	MGS 99	MGS 117	MGS 118	MGS 119	MGS 99	MGS 117	MGS 118	MGS 119	MGS 99	MGS 117	MGS 118	MGS 119
1	0·126	0·054	0·591	0·009	0·124	..	0·609	..	0·127	0·056	..	0·010
	0·128	0·052	0·585	0·010	0·122	..	0·610	..	0·128	0·056	..	0·0105
	0·125	0·055	0·580	0·010	0·127	..	0·606	..	0·127	0·057	..	0·0105
2	0·118	0·054	0·594	..	0·124	0·060	0·612	..	..	0·056	0·597	..
	0·122	0·056	0·586	..	0·122	0·062	0·606	..	..	0·057	0·609	..
	0·122	0·059	0·596	..	..	0·059	0·617	..	..	0·057	0·594	..
3	0·126	0·055	0·601	0·009	..	0·056	0·608	0·009	..	0·054	0·603	0·009
	0·125	0·055	0·615	0·009	..	0·055	0·611	0·010	..	0·054	0·607	0·009
4	0·124	0·057	..	0·012	..	0·058	..	..	0·124	0·058	..	..
	0·125	0·057	..	..	..	0·059	..	..	0·121	0·058	..	..
	0·124	0·059	..	..	..	0·058	..	..	0·122	0·058	..	..
5	0·132	0·055	0·591	0·007	0·134	0·060	0·595	0·009	0·129	0·058	..	0·010
	0·132	0·053	0·586	0·007	0·135	0·060	0·599	0·009	0·133	0·059	..	0·008
	0·125	0·053	0·585	0·009	0·137	0·060	0·599	0·009	..	..	..	..
6	0·122	0·056	..	0·012	0·117	0·058	0·613	0·009	0·120	0·052	0·613	0·010
	..	..	..	..	..	..	0·614	..	..	..	0·592	..
	..	..	..	..	..	..	..	..	..	..	..	..
7	0·126	0·057	..	0·018	..	..	..	..	..	..	..	..
	0·115	0·054	..	..	..	..	..	..	..	..	..	..
	0·117	..	..	..	..	..	..	..	..	..	..	..
8	0·125	..	0·615	..	0·123	0·057	0·611	0·009	0·131	0·057	0·605	0·009
	0·127	..	0·609	..	0·126	0·057	0·611	0·009	0·129	0·057	0·599	0·010
	..	..	0·609	..	0·126	0·057	0·609	0·010	0·129	0·059	0·591	0·010
9	0·118	..	0·60	..	..	..	0·60	..	..	..	0·60	..
	0·114	..	..	..	..	..	..	..	..	..	..	..

additional treatment of the tungstic acid precipitate is included whereby minor tin losses can be recovered.

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3. "Determination of Tin in Highly Alloyed Steels." *Journal of The Iron and Steel Institute*, 1950, vol. 165, p. 190.
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Appendix

METHODS FOR THE DETERMINATION OF TIN IN FERRO-TUNGSTEN AND TUNGSTEN METAL

METHOD I—CITRATE-SULPHIDE METHOD

Introduction

Principle—The sample is decomposed with sulphuric, hydrofluoric, and nitric acids, evaporated to fumes and the fumed concentrate extracted in citric acid. Tungsten is complexed by digestion in ammoniacal citrate solution and remains in stable solution throughout the succeeding operations. Tin is precipitated as sulphide using molybdenum sulphide as a carrier. The sulphide is separated and redissolved, the tin is reduced to the bivalent condition with metallic aluminium in the presence of an antimony salt, and the reduced tin is titrated with standard iodate solution.

Range—Up to 0·6% Sn.

Reproducibility—Replicate determinations at the 0·5% tin level should not differ by more than ±0·01% Sn.

Special Apparatus Required

(*a*) A suitable assembly for reduction of the tin consists of a 350-ml. conical flask, marked at 200 ml. and having a neck of about 1-in. dia. The flask is fitted with a bung holding a glass tube of ¼-in. bore, which protrudes about ½ in. into the flask below the base of the bung and externally is bent so as to overhang the edge of the hot plate. Grade *A* graduated glassware shall be used.

Reagents Required

All reagents shall be of the highest purity obtainable, and distilled water shall be used throughout. Solutions shall be freshly prepared and, where necessary, filtered. Details of the solutions required are as follows :

Sulphuric Acid (1 : 1)—Add 500 ml. of sulphuric acid (sp. gr. 1·84) cautiously, with stirring, to about 450 ml. of water, cool, and dilute to 1 litre.

Citric Acid (20%)—Dissolve 200 g. of citric acid in water and dilute to 1 litre.

Ammonium Molybdate (1%)—Dissolve 1 g. of ammonium molybdate crystals ($(NH_4)_6Mo_7O_{24}.4H_2O$) in water and dilute to 100 ml.

Acid Sulphide Wash—To about 900 ml. of water, add 10 ml. of sulphuric acid (sp. gr. 1·84), dilute to 1 litre and pass hydrogen sulphide gas through the solution until saturated.

Ferric Chloride—Dissolve 0·5 g. of pure tin-free iron in 20 ml. of hydrochloric acid (sp. gr. 1·16) and oxidize with the minimum amount of nitric acid (sp. gr. 1·42), added dropwise. Boil to expel nitrous fumes, cool, and dilute to 100 ml.

Hydrochloric Acid (1 : 1)—Dilute 500 ml. of hydrochloric acid (sp. gr. 1·16) to 1 litre.

Antimony Chloride—Treat 0·5 g. of powdered antimony with 5 ml. of sulphuric acid (sp. gr. 1·84) and fume for 5 min. Cool, dissolve in a mixture of 20 ml. of hydrochloric acid (sp. gr. 1·16) and 50 ml. of water, boil for 5 min., cool, and dilute to 100 ml.

Sodium Bicarbonate (10%)—Dissolve 100 g. of sodium bicarbonate in water* and dilute to 1 litre.

Potassium Iodide (10%)—Dissolve 10 g. of potassium iodide in water* and dilute to 100 ml. This solution must be freshly prepared and free from iodate.

Starch—Make a suspension of 4 g. of powdered starch in 50 ml. of water and add carefully to 450 ml. of boiling water. Cool before use. This solution must be freshly prepared.

Potassium Iodate (N/100)—Dissolve 0·3567 g. of potassium iodate in water and dilute to exactly 1 litre.*

Sampling

Recommended methods of obtaining a suitable sample for the analytical procedure outlined below are described in B.S. . . . †

Procedure

Transfer 2 g. (*see* Note I below) of powdered sample (— 90 mesh) to a covered platinum crucible (Note 2). Add 5 ml. of sulphuric acid (1 : 1), 5 ml. of hydrofluoric acid, and dissolve the sample by adding nitric acid (sp. gr. 1·42), a few drops at a time, replacing the cover after each addition. When the sample is completely decomposed, rinse the cover and sides of the crucible with distilled water, and add 10 ml. of sulphuric acid (1 : 1). Evaporate under a radiant heater until fumes of sulphur trioxide are evolved and continue fuming lightly for about 1 hr. to ensure removal of both fluoride and nitrate.

Allow the crucible to cool and extract the 'sulphated' concentrate in 100 ml. of citric acid (20%) contained in a 600-ml. squat beaker. Rinse and remove the crucible. Neutralize the citric acid extract with ammonium hydroxide (sp. gr. 0·880) and add 10 ml. excess. Heat to ensure solution of all tungstic acid, re-acidify with sulphuric acid (1 : 1), and add 5 ml. excess.

Dilute the solution to about 450 ml., heat to boiling, add 2 ml. of ammonium molybdate (1%), and then pass a brisk stream of hydrogen sulphide through the solution for 1 hr. Allow to stand (preferably overnight), filter through a pulp pad and wash the precipitated sulphides with sulphide wash.

Return the pad and precipitate to the original beaker, add 25 ml. of nitric acid (sp. gr. 1·42), 10 ml. of sulphuric acid (sp. gr. 1·84), and evaporate to fumes of sulphur trioxide, adding more nitric acid if

* Solutions of bicarbonate, iodide, starch, and iodate should be as free from dissolved oxygen as practicable. It is, therefore, necessary to use freshly boiled distilled water for making these solutions.

† In course of preparation.

necessary (Note 3). Cool, extract the fumed solution with 100 ml. of water and 15 ml. of hydrochloric acid (sp. gr. 1·16), and heat to boiling. A small amount of tungstic acid may precipitate at this stage, and in this event filter the solution through a pulp pad and wash with hydrochloric acid (1 : 19).

Add 5 ml. of ferric chloride solution, boil, and add ammonium hydroxide (1 : 1) cautiously to the boiling liquid until the solution is alkaline, filter the precipitated hydroxides of iron and tin through a No. 541 paper and wash with hot water. Dissolve the precipitate by pouring 140 ml. of hot hydrochloric acid (1 : 1) through the paper, collecting the solution in a flask (*see* " Special Apparatus Required "), and finally wash several times with hot hydrochloric acid (1 : 19).

Add to the solution 2 ml. of antimony chloride solution, dilute to 200 ml. with water, and place on a hot plate (Note 4). When nearly boiling, add carefully tin-free aluminium (millings, drillings, or foil) in small amounts until approx. 1 g. has been added. To the neck of the flask, before final solution of the last addition of aluminium, fit a bung with bent delivery tube (*see* " Special Apparatus Required "). Bring to the boil and continue boiling for 30 min., allowing the condensate to drip into a beaker for discard. After 30 min. boiling, immediately immerse the end of the delivery tube in 200 ml. of sodium bicarbonate solution (10%) contained in a tall-form 300-ml. beaker. Allow to suck back and evolve carbon dioxide, and then cool the flask in running water, keeping the end of the delivery tube immersed until quite cold (15–20° C.).

Remove the bung, add 10 ml. of potassium iodide solution (10%) and 20 ml. of starch solution. Titrate with potassium iodate solution (N/100) to a permanent blue colour, using a 10 ml. or 25 ml. burette of not more than 8 mm. internal dia.

Calculation

1 ml. of potassium iodate (N/100) is equivalent to 0·5935 mg. of tin, or 0·0297% of tin on a 2-g. sample.

METHOD II—TUNGSTEN SEPARATION METHOD

Introduction

Principle—The sample is decomposed and the fumed concentrate extracted, as in Method I. Tungsten is removed as tungstic acid and tin is determined directly in the filtrate, after reduction with metallic aluminium in the presence of an antimony salt, by titration with standard iodate solution.

Range—As for Method I.

Reproducibility—As for Method I.

Special Apparatus Required

As for Method I.

Reagents Required

All reagents shall be of the highest purity obtainable and distilled water shall be used throughout. Solutions shall be freshly prepared and, where necessary, filtered. Particulars of the solutions common to both Methods I and II are given under Method I. Details of the additional solutions required are as follows :

Hydrochloric Acid (1 : 19)—Dilute 50 ml. of hydrochloric acid (sp. gr. 1·16) to 1 litre with water.

Ammonium Hydroxide (1 : 1)—Dilute 500 ml. of ammonium hydroxide (sp. gr. 0·880) to 1 litre.

Sampling

As for Method I.

Procedure

Decompose 2 g. of powdered sample by the mixed acid procedure and evaporate to remove fluoride and nitrate exactly as in Method I.

Allow the crucible to cool and transfer the ' sulphated ' concentrate to a 600-ml. squat beaker by means of a jet of water. Rinse the crucible first with 25 ml. of hydrochloric acid (sp. gr. 1·16) and then with water, and adjust the total volume of the extract to 100 ml. Boil gently for 10 min., remove from the source of heat, and allow to settle for not less than 2 hr., preferably overnight.

Filter the tungstic acid precipitate on a No. 540 paper and wash with hydrochloric acid (1 : 19). Discard the precipitate (Note 5). Neutralize the filtrate with ammonium hydroxide (1 : 1) and add an excess of 10 ml. Boil for 2 min., filter through a No. 541 paper and wash with hot water. Dissolve the precipitate by passing 140 ml. of hot hydrochloric acid (1 : 1) through the paper, collecting the solution in a 350-ml. conical flask (*see* " Special Apparatus Required "), and finally wash several times with hot hydrochloric acid (1 : 19).

Add to the solution 2 ml. of antimony chloride solution and proceed as for Method I.

Calculation

As for Method I.

NOTES

(1) The weight specified is suitable for tin contents up to 0·6%. For alloys containing more than this amount of tin, a proportionately reduced initial weight may be taken.

(2) A crucible 5 cm. × 4½ cm. top dia., capacity 50 ml., is suitable. Alternatively, a dish, preferably of 100-ml. capacity, may be used.

(3) Oxidation and fuming must be repeated until all organic matter is destroyed.

(4) A blank determination on all reagents used in the process should be made under the same conditions.

(5) Traces of stannic oxide in the tungstic acid precipitate may be recovered by rinsing the tungstic acid precipitate from the paper, with a jet of water, into the original beaker and treating as follows : To the aqueous suspension add the equivalent of 2 mg. of iron (10 ml. of a solution prepared by dissolving 0·02 g. of pure iron in 10 ml. of hydrochloric acid (sp. gr. 1·16), oxidizing with nitric acid, boiling to expel nitrous fumes and making up to 100 ml.). Add 50 ml. of ammonium hydroxide (1 : 1), digest until the tungstic acid is dissolved, filter through a No. 541 paper, and wash with dilute ammonium hydroxide (1 : 49). Dissolve the precipitate from the paper with 20 ml. of hot dilute hydrochloric acid (1 : 1), rinse the paper several times with hot water, and add the acid extract and rinsings to the main solution.

Cold Rolling with Strip Tension

Part I—A NEW APPROXIMATE METHOD OF CALCULATION AND A COMPARISON WITH OTHER METHODS

By H. Ford, D.Sc.(Eng.), Ph.D., Wh.Sc., M.I.Mech.E., F. Ellis, B.Sc.(Eng.), and D. R. Bland, M.A.

SYNOPSIS

It is shown that, by making certain approximations to Orowan's general theory of rolling, it is possible to calculate roll force and torque by a method which is both rapid and easy to apply, using the basic information on the yield-stress characteristic of the material to be rolled, the coefficient of friction, and the dimensions of the pass.

The roll force and roll torque functions used in the calculations are presented in graphical form, the particular values required being read off from the curves in terms of the pass dimensions. Various methods of calculating these quantities for strip rolling with tensions have previously been put forward, and this paper examines the methods of Orowan, Hill, Siebel, Tselikov, and Nádai, and compares them with the new method for a wide range of tensions. The new method can be more quickly applied than any of the other methods examined.

Introduction

In an earlier paper[1] an account was given of experiments on cold strip rolling where no tension was applied to the strip, and the available theories of rolling were examined in relation to the experimental results. Also, it was shown in a companion paper[2] that certain approximations and limiting assumptions could be made to Orowan's general theory of rolling[3] for the practical range of cold-rolling conditions, without serious loss of accuracy.

All theories of rolling make some assumptions and approximations, and the usefulness of a theory can be judged only by reference to experiment. For general use, a method of calculating the important quantities —roll torque, roll force, and power consumption, for example—is required such that the calculations can be performed reasonably quickly and without demanding any difficult mathematical operations. From a practical point of view the validity of the theory is of lesser importance, so long as, over a wide range of the variables involved, fair accuracy and reliability are secured.

In the earlier papers[1,2] a simplified theory was used for calculating roll force and torque, for comparison with a large number of readings taken on the experimental 2-high cold-rolling mill at Sheffield; but at that time very few results had been obtained in which tension was applied to the strip, and it was not possible to test any of the rolling theories for the tension case. It was pointed out at the time, however, that it should be possible to develop the simplified theory for rapid calculations when tensions are applied to the strip, in a way similar to that which had been demonstrated for 'no-tension' rolling.

The comparison of theory and experiment in tension rolling should provide a more searching test of the usefulness or otherwise of the theories or calculation methods, as it is possible to vary the roll force and torque over a much greater range than in simple sheet rolling without tension. It is expected that the programme of experimental work being carried out by the Rolling Section of the British Iron and Steel Research Association will make available, in the near future, values of roll force and torque for tension rolling, and the simplified theory referred to above was therefore extended to cover strip rolling with tension. This paper describes the computational work which had to be carried out, and presents the results graphically, in a form which allows roll force and torque to be calculated rapidly and simply.

Notation

The following symbols are used:

a = non-dimensional group = $\mu\sqrt{\frac{R'}{h_2}}$

b = tension factor = $\frac{1-\frac{\sigma_2}{\bar{k}}}{1-\frac{\sigma_1}{\bar{k}}}$

$B = \log_e b$

c = constant in Hitchcock's equation

f = horizontal force in the rolled material

f_3, defined by equation (6)

f_5, defined by equation (7)

G = torque per unit width per roll

h = thickness of the strip at any point

$H = 2\sqrt{\frac{R'}{h_2}}\tan^{-1}\left(\sqrt{\frac{R'}{h_2}}\phi\right)$, a function of the geometry of the pass

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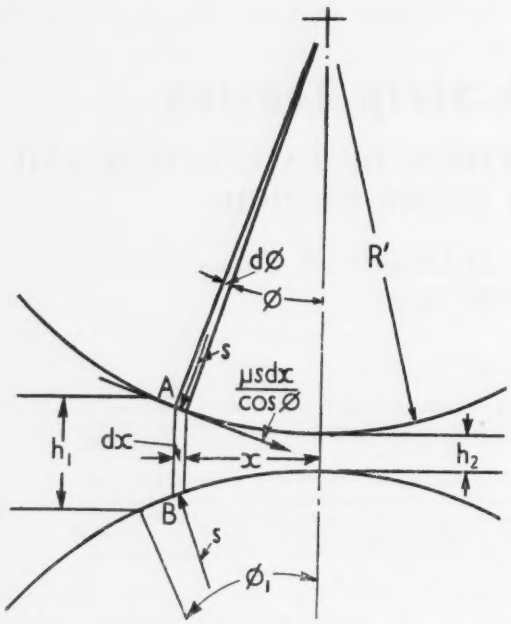

Fig. 1—Element in roll gap

k = yield stress at any point
m = forward slip
p = horizontal pressure in the rolled material $= f/h$
P = roll force per unit width
r = fractional reduction in the pass
R = undeformed roll radius
R' = deformed roll radius
s = normal roll pressure at any point
w, a factor to allow for non-homogeneous compression in Orowan's theory
x = distance of a point in the roll gap from the plane of exit $= R'\phi$
δ = absolute reduction in pass $= h_1 - h_2$
Δh = absolute reduction at any point $= h_1 - h$
μ = coefficient of friction between the strip and the roll
ρ = fractional reduction at any point $= \dfrac{\Delta h}{h_1}$
σ = tension expressed as a stress
ϕ = angular co-ordinate of a point on the arc of contact.

Suffixes

$_0$ refers to annealed material
$_1$ refers to conditions at entry
$_2$ refers to conditions at exit
$_n$ refers to conditions at the neutral point
A bar thus ($\bar{k}$) denotes ' mean value of.'

DEVELOPMENT OF THE THEORY OF COLD ROLLING

In the previous paper,[2] it was shown that, if certain approximations are made, the normal roll pressure s (*see* Fig. 1) can be expressed by :

$$s^+ = \frac{kh}{h_2}\left(1 - \frac{\sigma_2}{k_2}\right)e^{\mu H} \quad \text{.....(1)}$$

from the exit to the neutral point, and :

$$s^- = \frac{kh}{h_1}\left(1 - \frac{\sigma_1}{k_1}\right)e^{\mu(H_1 - H)} \quad \text{.....(2)}$$

from the entry to the neutral point, where :

k = value of the yield stress with inhibited spread, at any point in the arc of contact
k_1 = yield stress with inhibited spread, at the entry point
k_2 = yield stress with inhibited spread, at the exit point
σ_1 = back tension, expressed as a stress
σ_2 = front tension, expressed as a stress
H_1 = value of H at the entry point

$$= 2\sqrt{\frac{R'}{h_2}}\tan^{-1}\left(\sqrt{\frac{R'}{h_2}}\,\phi_1\right)$$

R' = radius of the flattened arc of contact, obtained from Hitchcock's formula
h_1 = thickness of the strip at entry
h_2 = thickness of the strip at exit
ϕ_1 = angle subtended at the entry point

$$= \sqrt{\frac{h_1 - h_2}{R'}}.$$

This theory is based on Orowan's Homogeneous Graphical Method,[3] but with some additional approximations to allow the equation to be integrated. Equations (1) and (2) depend upon the variation of k, h, and ϕ (and consequently H), throughout the arc of contact, as in Orowan's method, and the total roll force and the torque are obtained by a stepwise integration. As with Orowan's theories, the variation of $\bar{k}$ with work-hardening as reduction proceeds in the pass is taken into account but the computational work is not so arduous. Examples of its use were given in the earlier paper, and the pressure distributions were compared with those given by Orowan's theory.

The roll force is obtained from the expression :

$$P = R'\int_0^{\phi_n} s^+ d\phi + R'\int_{\phi_n}^{\phi_1} s^- d\phi \quad \text{.....(3)}$$

where ϕ_n, the angle of the neutral point, is given by the equations :

$$\phi_n = \sqrt{\frac{h_2}{R'}}\tan\left(\sqrt{\frac{h_2}{R'}} \times \frac{H_n}{2}\right)$$

and $$H_n = \frac{H_1}{2} - \frac{1}{2\mu}\log_e \frac{h_1}{h_2}\left\{\frac{1 - \sigma_2/k_2}{1 - \sigma_1/k_1}\right\}.$$

The torque is given by the expression :

$$G = RR'\left[\int_0^{\phi_1} s\phi d\phi + \frac{(\sigma_1 h_1 - \sigma_2 h_2)}{2R'}\right] \quad \text{.....(4)}$$

In these equations, the tensions σ_1 and σ_2 are the numerical values, the signs having been allowed for in deducing the expressions.

SIMPLIFIED THEORY USING A CONSTANT MEAN YIELD STRESS

The difficulty in evaluating P from equation (3) lies in the fact that the yield stress k occurs as a variable in equations (1) and (2) ; as the variation of the yield stress with degree of reduction cannot be expressed generally by a mathematical function, a stepwise evaluation is therefore necessary.

In some theories a mean yield stress has been used, and in the previous papers[1, 2] it was shown that the error introduced by this approximation was never more than 2%* for cold rolling without tension, if

* Except for *roll torques* of first passes on annealed strip, where the value calculated by the mean yield stress method may be up to 10 % too high.

the mean yield stress was calculated using the expression :

$$\bar{k} = \frac{\int_0^{\phi_1} k\,d\phi}{\int_0^{\phi_1} d\phi} = \frac{\int_0^{\phi_1} k\,d\phi}{\phi_1}, \quad \ldots\ldots\ldots\ldots\ldots(5)$$

that is, if the true mean value is used. The mean yield stress $\bar{k}$ is calculated from the yield stress curve by taking five or more steps in the way shown on p. 63.

When $\bar{k}$ is taken as constant, the expressions for roll force and torque can be expressed in terms of certain non-dimensional groups of the dimensions of the pass, and the difficult integrations can be carried out once and for all over the whole practical range of the groups. The results can be plotted in graphical form.

The expression for roll force is :

$$P = \bar{k}\left\{\sqrt{R'(h_1 - h_2)}\right\}\left\{\left(1 - \frac{\sigma_1}{\bar{k}}\right)\right\} \times f_3(a, r, b) \ldots(6)$$

where :

$\sqrt{R'(h_1 - h_2)}$ = length of the arc of contact
σ_1 = back tension, expressed as a stress
$f_3(a, r, b)$ = non-dimensional roll force function obtained from curves
σ_2 = front tension expressed as a stress.

The expression for roll torque is :

$$G = R\bar{k}(h_1 - h_2)\left(1 - \frac{\sigma_1}{\bar{k}}\right) f_5(a, r, b) \ldots\ldots\ldots\ldots(7)$$

where $f_5(a, r, b)$ = non-dimensional roll torque function
G = torque per unit width per roll.

The derivation of these expressions, and the details of the functions f_3 and f_5, are given in Appendix I.

The evaluation of P and G from equations (6) and (7) is not difficult, and only known quantities are involved. The functions, which are read off curves, depend upon three non-dimensional variables, a, r, and b, and a double interpolation may therefore be necessary, though this presents no difficulty. Examples will be given later in the paper.

PREPARATION OF THE GRAPHS OF f_3 AND f_5

The calculation of roll force and torque by use of equations (6) and (7), as has already been pointed out, requires that the two functions $f_3(a, r, b)$ and $f_5(a, r, b)$ shall be calculated over the complete range of values of a, r, and b. There are certain limits to these quantities, determined by (i) the practical values of μ, the coefficient of friction in cold rolling ; (ii) the maximum back tension that can be applied for a given value of μ (so that skidding does not occur) ; and (iii) the maximum front tension that can be applied corresponding to the point where the roll torque is zero. The governing equations are given in Appendix I. From these equations it is possible to work out the limiting pass reductions r, for given values of b and a obtained from the pass data. The functions are then calculated at values of r between the limiting values.

For ease in calculating the functions, the non-dimensional group b was replaced by its Naperian logarithm B, *i.e.*,

$$B = \log_e b = \log_e \left\{\frac{1 - \sigma_2/\bar{k}}{1 - \sigma_1/\bar{k}}\right\}.$$

The functions f_3 and f_5 have been computed over the range of r from 0·05 to 0·90, for the practical ranges of a and B. In some cases the practical range of r is smaller, as determined by the equations given in Appendix I. From experience and from some preliminary calculations, it was decided that values of a between 0·5 and 2·5 should be used : curves of f_3 and f_5 against a for a given value of B were found to be fairly flat, and it was decided that it would be sufficient if the functions were calculated for $a = 0{\cdot}5$, 0·75, 1·0, 1·5, 2·0, and 2·5.

Similar considerations showed that values of B of

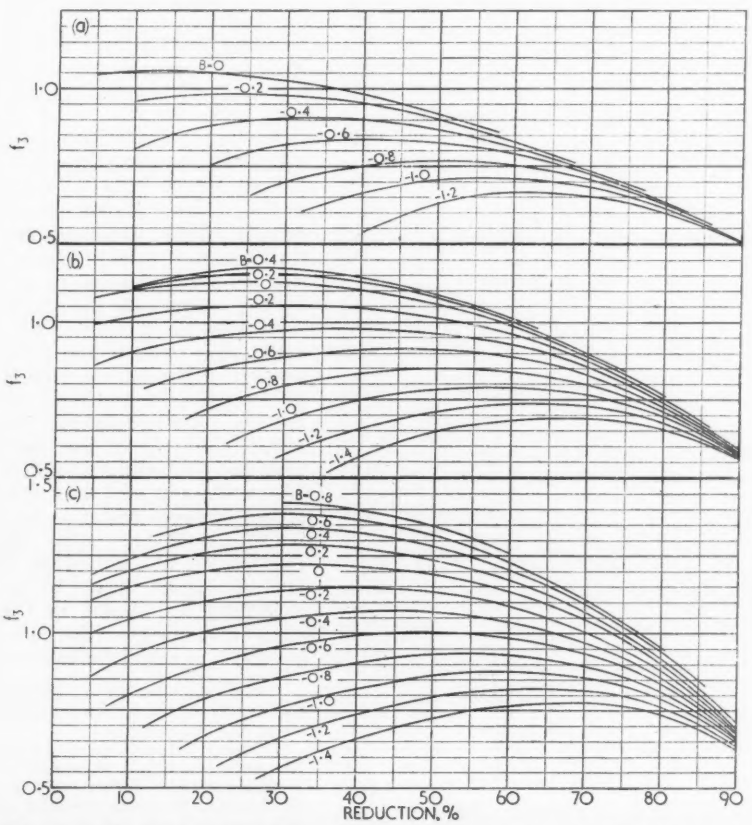

Fig. 2—Calculated values of function f_3: (a) $a = 0{\cdot}5$; (b) $a = 0{\cdot}75$; (c) $a = 1{\cdot}0$

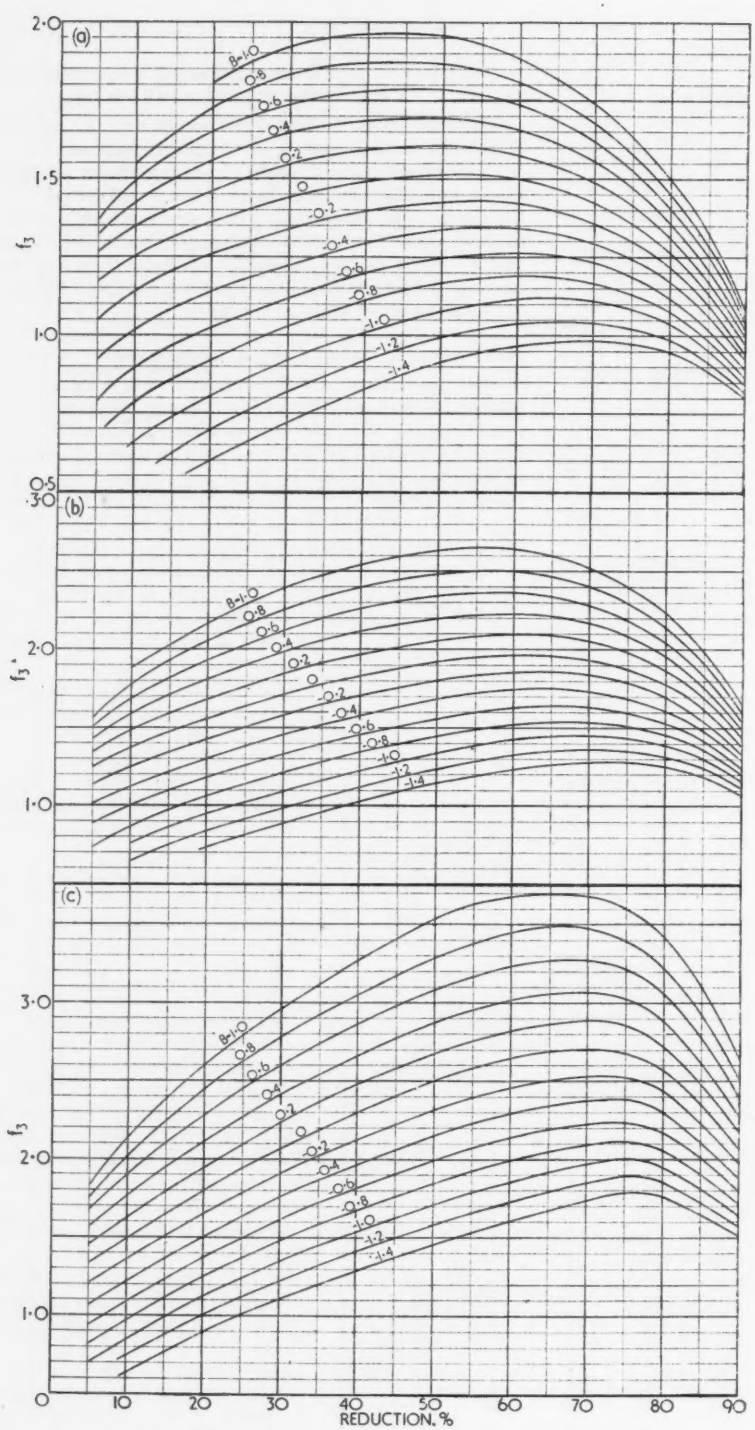

Fig. 3—Calculated values of function f_3: (*a*) $a = 1 \cdot 5$; (*b*) $a = 2 \cdot 0$; (*c*) $a = 2 \cdot 5$

$+ 0 \cdot 75, 0, - 0 \cdot 75$, and $- 1 \cdot 5$, would be sufficient. Originally, for values of a of $0 \cdot 5$ and $2 \cdot 5$, values of f_3 and f_5 had been computed for $B = + 0 \cdot 75$, $+ 0 \cdot 5, + 0 \cdot 25, 0, - 0 \cdot 25, - 0 \cdot 5$, $- 0 \cdot 75$, $- 1 \cdot 0$, and $- 1 \cdot 25$; but when the curves were drawn against B as abscissa, they were found to be very flat, so that for the rest of the calculations the values of B were reduced to the four given above.

The calculations of the functions of f_3 and f_5 were carried out by the Mathematics Department* of the National Physical Laboratory.†

The interval of B of $0 \cdot 75$ was not convenient for interpolation on the graphs of f_3 and f_5; accordingly, new values were prepared by plotting and replotting the original data in various ways, so that, finally, curves of the functions could be given at intervals of B of $0 \cdot 2$ over the appropriate range for each value of a. The resulting graphs are given in Figs. 2–5.

Examples of the Use of the Graphs

Example 1—Mild-steel strip, $0 \cdot 0625$ in. thick initially, is to be rolled to $0 \cdot 0255$ in. thick in two passes. A first pass of 40% is made, so reducing the thickness to $0 \cdot 0383$ in. Calculate the roll force and torque for the second pass for a 6-in. wide strip, rolled in a mill with 10-in. dia. rolls, if the front tension in the second pass is $20 \cdot 4$ tons/sq. in. and the back tension is $5 \cdot 9$ tons/sq. in. The mean yield stress has been previously determined as $\bar{k} = 45 \cdot 0$ tons/sq. in., and the radius of the flattened arc of contact is $R' = 6 \cdot 69$ in. (If this information was not given, $\bar{k}$ and R' would have to be calculated as shown in the next example.) Take $\mu = 0 \cdot 086$; $h_1 =$ initial thickness =

* The authors are indebted to Mr. T. Vickers, who supervised the calculations.

† Owing to space limitations, the values are not reproduced. Details may be obtained from the Mechanical Working Division of the British Iron and Steel Research Association.

$0{\cdot}0383$ in.; and h_2 = final thickness = $0{\cdot}0255$ in.

(i) Reduction in the pass $= \delta = (h_1 - h_2)$
$= 0{\cdot}0128$ in.

$$\therefore r = \frac{0{\cdot}0128}{0{\cdot}0383} = 33{\cdot}2\,\%.$$

Calculate a and B:

(ii) $$a = \mu\sqrt{\frac{R'}{h_2}} = 0{\cdot}086\sqrt{\frac{6{\cdot}69}{0{\cdot}0255}} = 1{\cdot}39$$

(iii) $$1 - \frac{\sigma_1}{k} = 0{\cdot}869 \text{ and } 1 - \frac{\sigma_2}{k} = 0{\cdot}548$$

$$\therefore b = \frac{0{\cdot}548}{0{\cdot}869} = 0{\cdot}632 \text{ and } B = \log_e b = -0{\cdot}459.$$

The functions f_3 and f_5 can now be found from the graphs. For f_3, see Figs. 3*a* and 2*c* for $a = 1{\cdot}5$ and $1{\cdot}0$, which lie on either side of the value of a ($1{\cdot}39$) required for the problem. On curves $B = -0{\cdot}4$ and $-0{\cdot}6$, the values of f_3 can be read off at $r = 33{\cdot}2\%$. It will be found that:

(iv) For $a = 1{\cdot}5$,
at $B = -0{\cdot}4$, $f_3 = 1{\cdot}248$
at $B = -0{\cdot}6$, $f_3 = 1{\cdot}145$ } from Fig. 3*a*
difference $= 0{\cdot}103$

Thus, at $B = -0{\cdot}459$,

$$f_3 = 1{\cdot}145 + \frac{0{\cdot}141}{0{\cdot}20} \times 0{\cdot}103 = 1{\cdot}218.$$

(v) For $a = 1{\cdot}0$,
at $B = -0{\cdot}4$, $f_3 = 1{\cdot}058$
at $B = -0{\cdot}6$, $f_3 = 0{\cdot}968$ } from Fig. 2*c*
difference $= 0{\cdot}090$

Thus, at $B = -0{\cdot}459$, by proportion as above,
$f_3 = 1{\cdot}025$.

(vi) Finally, for $a = 1{\cdot}39$,

$$f_3 = \frac{1{\cdot}218 - 1{\cdot}025}{0{\cdot}5} \times 0{\cdot}39 + 1{\cdot}025$$
$$= 1{\cdot}097,$$

by proportion between the two values of a.

(vii) $$\sqrt{R'(h_1 - h_2)} = 6{\cdot}69 \times 0{\cdot}0128 = 0{\cdot}293$$

(viii) Roll force $$P = k\sqrt{R'(h_1 - h_2)} \times \left\{1 - \frac{\sigma_1}{k}\right\} f_3$$
$$= 45{\cdot}0 \times 0{\cdot}293 \times 0{\cdot}869 \times 1{\cdot}097 \text{ tons/sq. in.}$$
$$= 12{\cdot}6 \text{ tons/sq. in.}$$

In practice, it is unnecessary to write down all the steps given in the above example. Steps (i), (vii), and (viii) are required in some form in all calculations of roll force by any theory, and steps (ii) and (iii) can be performed in a few seconds with a slide rule and log tables. Steps (iv) and (v) can usually be carried out by visual interpolation with sufficient accuracy, the values of f_3 of $1{\cdot}218$ and $1{\cdot}025$ being

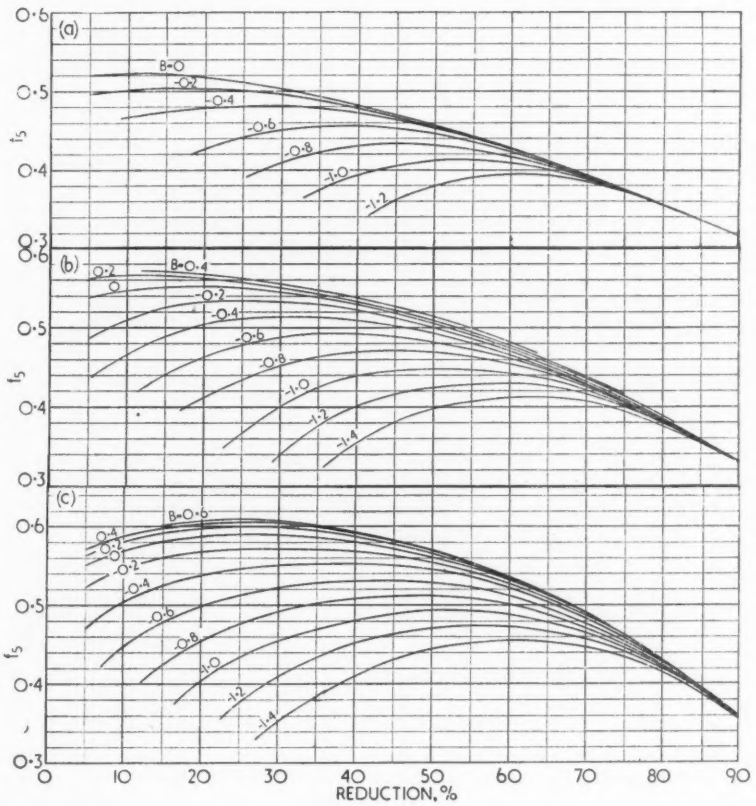

Fig. 4—Calculated values of function f_5: (*a*) $a = 0{\cdot}5$; (*b*) $a = 0{\cdot}75$; (*c*) $a = 1{\cdot}0$

written down at once from the graphs. Step (vi) requires only a few seconds.

For the roll torque, referring to Figs. 5*a* and 4*c*:

(ix) For $a = 1{\cdot}5$,
at $B = -0{\cdot}4$, $f_5 = 0{\cdot}648$
at $B = -0{\cdot}6$, $f_5 = 0{\cdot}621$ } from Fig. 5*a*
difference $= 0{\cdot}027$
Thus at $B = -0{\cdot}459$, by proportion,
$f_5 = 0{\cdot}642$.

(x) For $a = 1{\cdot}0$,
at $B = -0{\cdot}4$, $f_5 = 0{\cdot}552$
at $B = -0{\cdot}6$, $f_5 = 0{\cdot}527$ } from Fig. 4*c*
difference $= 0{\cdot}025$
Thus at $B = -0{\cdot}459$, by proportion,
$f_5 = 0{\cdot}544$.

(xi) Finally, for $a = 1{\cdot}39$,

$$f_5 = \frac{0{\cdot}642 - 0{\cdot}544}{0{\cdot}5} \times 0{\cdot}39 + 0{\cdot}544 = 0{\cdot}620.$$

(xii) $R\delta = \frac{10}{2} \times 0{\cdot}0128 = 0{\cdot}0639$

(xiii) $\sigma_1 h_1 = 0{\cdot}226$; $\sigma_2 h_2 = 0{\cdot}540$

(xiv) $$G = \bar{k}(R\delta)\left\{1 - \frac{\sigma_1}{\bar{k}}\right\} f_5 + \frac{R}{2}(\sigma_1 h_1 - \sigma_2 h_2)$$
$$= 45 \times 0{\cdot}0639 \times 0{\cdot}869 \times 0{\cdot}620 - 0{\cdot}784$$
$$= 0{\cdot}77 \text{ tons-in./in.}$$

Total roll force $= 6 \times 12{\cdot}6 = 75{\cdot}6$ tons.
Total torque $= 2 \times 6 \times 0{\cdot}77 = 9{\cdot}24$ tons-in.

Example 2—High-conductivity copper, initially 0·1 in. thick in the annealed condition, is to be rolled to 0·06 in. thick in one pass in a mill with 14-in. dia. rolls. The coefficient of friction $\mu = 0{\cdot}07$; front tension = 10 tons/sq. in.; back tension = 7·9 tons/sq. in. The yield-stress curve is shown in Fig. 6. Find the roll force per inch width of strip, and the torque per inch width.

First, the mean yield stress must be found. A

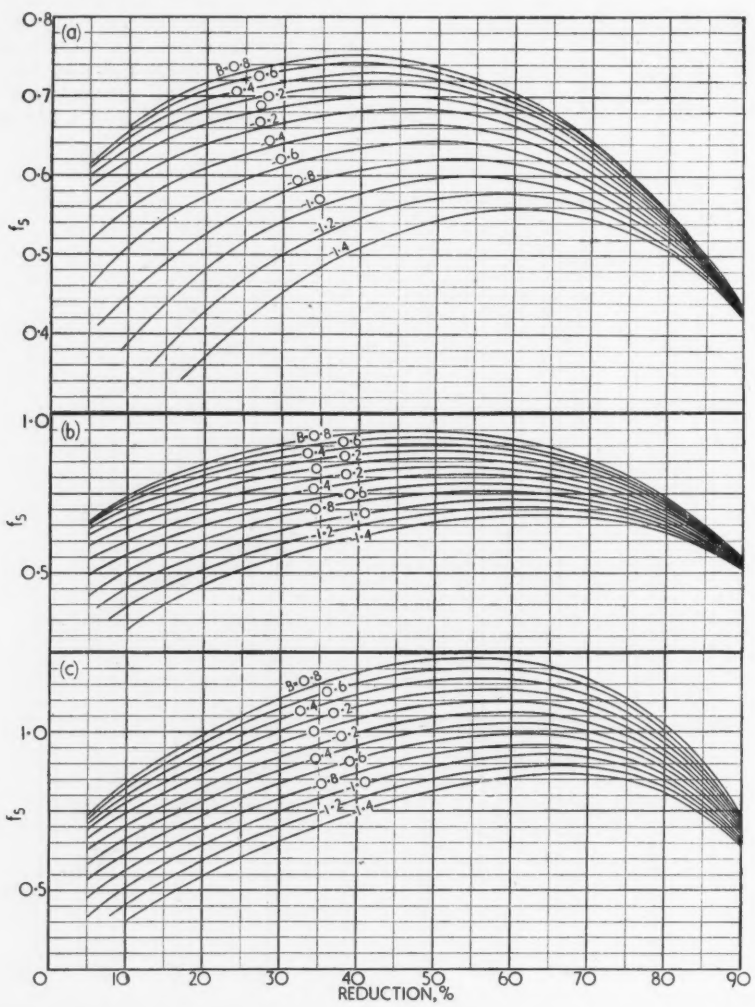

Fig. 5—Calculated values of function f_5: (*a*) $a = 1{\cdot}5$; (*b*) $a = 2{\cdot}0$; (*c*) $a = 2{\cdot}5$

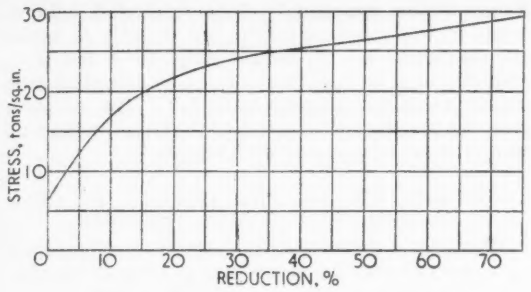

Fig. 6—Yield-stress curve for copper

method of calculating this stress is shown on p. 64. From Fig. 7:

$$\text{pass reduction} = \frac{0{\cdot}1 - 0{\cdot}06}{0{\cdot}1} = 40\,\%.$$

The intercepts in Fig. 7 are written down for a 40% reduction, and the corresponding values of k are read off from Fig. 6.

r, %	0	12·3	22·4	30·1	35·7	38·8	40
k	6·4	18·5	22·4	24·2	25·0	25·4	25·45

By mean ordinate rule, for the mean $\bar{k}$ from these values:

$$\bar{k} = \frac{(6{\cdot}4 + 25{\cdot}45) + 2(18{\cdot}5 + 22{\cdot}4 + 24{\cdot}2 + 25{\cdot}0 + 25{\cdot}4)}{2 \times 6}$$

$= 21{\cdot}9$ tons/sq. in.

First find an approximate roll force, to obtain a value of R' with which to start. The tensions will be ignored initially.

(i) From the approximate roll-force expression[4]

$$P = 1{\cdot}2\,\bar{k}\sqrt{R\delta} + (1{\cdot}2\,\bar{k})^2 cR + \ldots\ldots$$

where c = elastic constant of the rolls
$= 1{\cdot}67 \times 10^{-4}$ inch and ton units for steel rolls

$$\therefore P = 26{\cdot}3 \times 0{\cdot}53 + 6{\cdot}9 \times 10^2 \times 1{\cdot}67 \times 10^{-4} \times 7 \text{ tons/in.}$$

$= 14{\cdot}71$ tons/in.

From Hitchcock's formula:

$$R' = 7\left\{1 + \frac{2cP}{\delta}\right\} = 7\left\{1 + \frac{2 \times 1{\cdot}67 \times 10^{-4} \times 14{\cdot}7}{0{\cdot}04}\right\}$$

$\therefore R' \simeq 7{\cdot}9$ in.

Now proceed as before:

(ii) $a = 0{\cdot}07\sqrt{\dfrac{7{\cdot}9}{0{\cdot}06}} = 0{\cdot}806$

(iii) $1 - \dfrac{\sigma_1}{\bar{k}} = 1 - \dfrac{7{\cdot}9}{21{\cdot}9} = 0{\cdot}64$

$1 - \dfrac{\sigma_2}{\bar{k}} = 1 - \dfrac{10}{21{\cdot}9} = 0{\cdot}544$

$b = 1{\cdot}175$, $\therefore B = \log_e b = 0{\cdot}161$.

The nearest curves are at: $a = 0{\cdot}75$, $B = 0$
$a = 1{\cdot}0$, $B = 0{\cdot}2$.

(iv) At $a = 0{\cdot}75$, $f_3 = 1{\cdot}123$
(v) At $a = 1{\cdot}0$, $f_3 = 1{\cdot}265$
difference $= 0{\cdot}142$

(vi) Thus, at $a = 0{\cdot}806$,

$$f_3 = \frac{0{\cdot}142}{0{\cdot}25} \times 0{\cdot}056 + 1{\cdot}123 = 1{\cdot}156$$

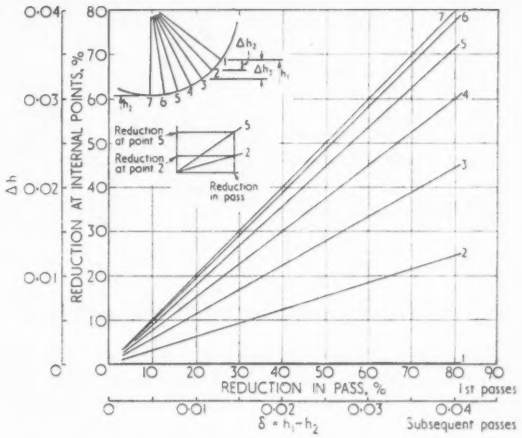

Fig. 7—Graphical form of equation (8) for $N = 6$

(vii) $\sqrt{R'(h_1 - h_2)} = \sqrt{7{\cdot}9 \times 0{\cdot}04} = 0{\cdot}563$

(viii) Roll force $P = 0{\cdot}563 \times 21{\cdot}9 \times 0{\cdot}64 \times 1{\cdot}156$
$= 9{\cdot}15$ tons/in.

The first estimate of the roll force (14·7 tons/in.) was therefore badly out. A second estimate of $P = 9{\cdot}0$ tons/in. was still a little too high, giving a calculated value of $P = 8{\cdot}85$ tons/in. Finally, P was estimated as 8·8 tons/in., and calculating by steps (i)–(viii) as before gave $P = 8{\cdot}8$ tons/in.

(ix) At $a = 0{\cdot}75$, $f_5 = 0{\cdot}533$
(x) At $a = 1{\cdot}0$, $f_5 = 0{\cdot}597$
difference $= 0{\cdot}064$

(xi) Thus, at $a = 0{\cdot}786$,

$$f_5 = \frac{0{\cdot}064}{0{\cdot}25} \times 0{\cdot}036 + 0{\cdot}533 = 0{\cdot}542.$$

$\therefore$ Roll torque $G = 21{\cdot}9 \times 7 \times 0{\cdot}04 \times 0{\cdot}64 \times 0{\cdot}542 + \frac{7}{2}(7{\cdot}9 \times 0{\cdot}1 - 10 \times 0{\cdot}06)$

$= 0{\cdot}971$ tons-in./inch per roll.

Roll force $= 8{\cdot}80$ tons/in.
Total roll torque $= 1{\cdot}94$ tons-in./in.

Note: Even though the first estimate of roll force was inaccurate, it was only necessary to repeat the calculation once, and only a few steps have to be recalculated. These calculations, including the determination of $\bar{k}$, were completed in 35 min., writing down all the steps. An average time when noting down only the results of the calculations is 20 min. It will be appreciated, therefore, that the method can be applied very quickly.

DETERMINATION OF MEAN YIELD STRESS

The calculation of the mean yield stress by equation (5) is the most serious part of the work, if the normal method of evaluation is used. This involves calculating the thickness h, at a number of equally spaced points in the roll gap, from the expression:

$$h = h_2 + R'\phi^2,$$

then finding the percentage reduction r corresponding to each of these points from the expression:

$$r\,\% = \frac{h_1 - h}{h_1} \times 100.$$

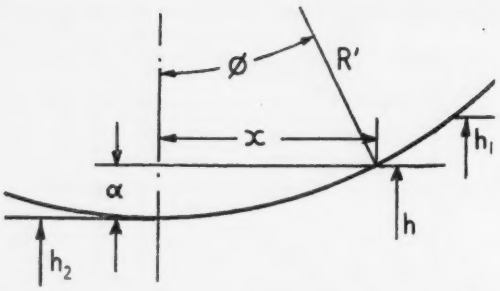

Fig. 8—Much enlarged section of rolls and strip

The values of k at each value of r can then be found from the yield-stress curve, and the mean value can be found by Simpson's rule or by the mean ordinate rule.

The amount of calculation can be considerably reduced by using a simple graphical construction. Since Hitchcock's formula gives a circular arc of contact, the mean yield stress is independent of the radius of curvature for a given reduction. Referring to Fig. 8, which shows an exaggerated section through the rolls and strip, with the usual approximations :

$$x = R'\phi$$

$$\therefore \frac{x^2}{R'} = R'\phi^2$$

$$\Delta h = h_1 - h$$

But $h = h_2 + R'\phi^2$

Hence $\Delta h = h_1 - h_2 - R'\phi^2 = \delta - R'\phi^2$.

Now suppose that the arc of contact is divided into N equal parts, *i.e.*, $\phi = \phi_1/N$. An intermediate point is given by an angle $\phi = \frac{\phi_1 n}{N}$, where n can have any integral value from 0 to N.

Then :

$$\Delta h = \delta - \frac{R'\phi_1{}^2 n^2}{N^2} = \delta\left(1 - \frac{n^2}{N^2}\right)$$

since $R'\phi_1{}^2 = \delta$. Therefore, for a given value of n, Δh is dependent only upon δ, the pass reduction.

For first passes :

$$\frac{\Delta h}{h_1} = \rho = \frac{\delta}{h_1}\left(1 - \frac{n^2}{N^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where ρ is the fractional reduction at any intermediate point in the arc of contact between 0 and r.

To give reasonable accuracy, the convenient number of ordinates for Simpson's rule is seven. Figure 7 shows the graphical form of equation (8) for $N = 6$, which gives seven ordinates.

For second or subsequent passes, the total percentage reduction from the start of the yield stress curve is required, and in this case the percentage reduction cannot be immediately obtained. The expression :

$$\Delta h = \delta\left(1 - \frac{n^2}{N^2}\right)$$

must be used. Now if r_1 = fractional reduction at the start of the pass, and ρ_T = total reduction at any point n in the pass, then :

$$\rho_T = r_1 + \frac{\Delta h}{h_o} = r_1 + \frac{\delta}{h_o}\left(1 - \frac{n^2}{N^2}\right) \quad \ldots\ldots\ldots (9)$$

where h_o = initial thickness of the strip.

Figure 7 has, accordingly, been calibrated both in terms of fractional reduction and directly in terms of pass reduction. To use the graph for a first pass, read off, on a vertical line at the pass reduction, the intercepts of the sloping lines 1–7. The ordinate gives the percentage reduction at the equal increments along the arc of contact (*see* Example 2).

CONSIDERATION OF THE METHOD IN COMPARISON WITH OTHER THEORIES

Most of the earlier simple theories of rolling have been worked out for sheet rolling without tension, and cannot readily be modified to cover tension rolling. There are some theories, however, which do allow for tensions, and a comparison with these theories will now be made.

The theories are :

(i) Orowan's general theory
(ii) Von Karman's method (called 'homogeneous-graphical' by Orowan)
(iii) Siebel's method[6]
(iv) Tselikov's method[7]
(v) Nádai's method[8]
(vi) Hill's method.[5]

The only experimental data available at present are those given by Hill,[5] who shows curves of $\frac{G}{PR}$ plotted against $\frac{\sigma_2 h_2 - \sigma_1 h_1}{P}$ for various values of the angle of contact. The material used was mild steel, initially 0·0635 in. thick and in the annealed condition, and the yield-stress curve is shown in Fig. 9. Samples of the material were supplied by the British Iron and Steel Research Association, both in the 'as received' (annealed) condition and also after various degrees of cold rolling. Careful tests* to determine the yield-stress curve were made at Imperial College, using an improved technique for compression in plane strain, in comparison to that described in the previous paper.[1] The curve in Fig. 9 is the mean through the points for all these determinations,† and it is believed that it represents a very close approach to the yield stress in plane strain for the strip used in the tests. The difference between the plane compression test curve and that for the tensile test was small (about 3%).

Comparison between the various calculation methods has therefore been made for this material, rolled in

* The authors are indebted to Mr. A. B. Watts for carrying out the tests.

† B.I.S.R.A. also made tests, and their curve agrees closely with the authors'.

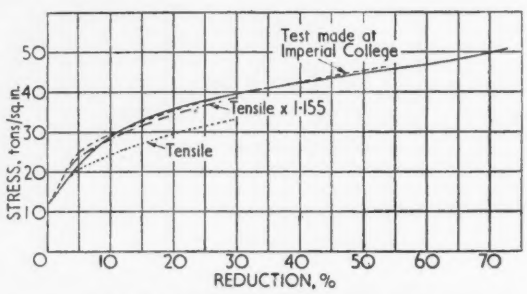

Fig. 9—Yield-stress curve for steel

a mill with 10-in. dia. rolls, using a soluble oil solution as lubricant. The coefficient of friction was taken as $\mu = 0{\cdot}063$, because this value was deduced by Hill from the experiments reported in his paper. The value of the coefficient of friction taken in cold-rolling calculations has been discussed elsewhere.[1] In the present case, since various theories, including that of Hill, are being compared, the convenient course is to accept the value given by Hill.

For the purposes of the calculations, geometrically similar passes were assumed with a constant angle of contact $\phi_1 = 0{\cdot}0655$. The choice of ϕ_1 as a constant is necessary because Hill's method requires data for a given angle of contact, rather than a given percentage pass reduction, and Hill's paper refers to the only experimental results so far available in published form. Since the radius of the flattened arc of contact varies with different conditions of tension, the assumption of a fixed angle of contact necessarily means a variation in exit thickness h_2, but in all cases the deviation from the nominal reduction of 40% for first passes is small.

Figure 10 is taken from Hill's paper, and shows the mean line for $\frac{G}{PR}$ plotted against $\frac{\sigma_2 h_2 - \sigma_1 h_1}{P}$ for the angle of contact chosen, and for the experimental values of G, P, σ_2, and σ_1.

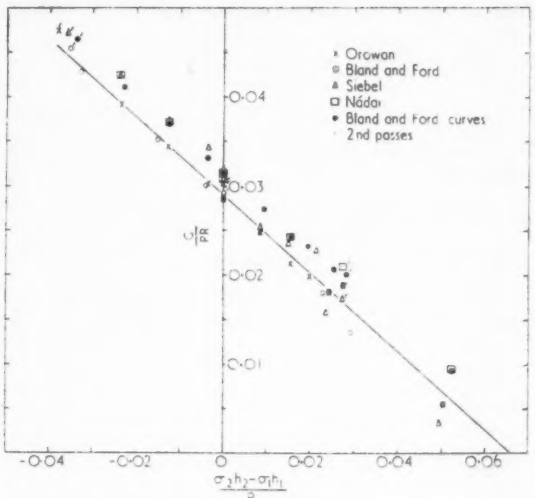

Fig. 10—Relation between $\frac{G}{PR}$ and $\frac{\sigma_2 h_2 - \sigma_1 h_1}{P}$ for $\phi_1 = 0{\cdot}0655$ radians, showing mean line through Hill's experimental points

Orowan's General Theory

Cook and Larke[8] have shown that Orowan's solution of the problem for cold rolling gives the horizontal force f in the material at any angle ϕ as :

$$\frac{f}{h} = 2R'e^{\mu(H_1 - H)}\int_{\phi_1}^{\phi} \frac{kw(\mu\cos\phi - \sin\phi)}{he^{\mu(H_1 - H)}}d\phi + \frac{f_1}{h_1} \quad \ldots(10)$$

for the entry side, and :

$$\frac{f}{h} = 2R'e^{\mu H}\int_{\phi_1}^{\phi} \frac{kw(\mu\cos\phi - \sin\phi)}{he^{\mu H}}d\phi + \frac{f_2}{h_2} \quad \ldots\ldots\ldots(11)$$

for the exit side, where the symbols have the meanings already attached to them, except that H is a function of ϕ and the ratio $h_2/2R'$ obtained from graphs given by Orowan, and w is a factor, to allow for non-homogeneous compression, obtained from Fig. 9 of Orowan's paper.

The roll pressure s, at any point ϕ, is found from :

$$s = \frac{f}{h} + kw \quad \ldots\ldots\ldots(12)$$

where f/h is the value found from equations (10) or (11), for the point on the entry or exit side of the neutral point, respectively ; k is the yield stress at the point ; and w is the non-homogeneity factor at the point. The roll force is then found from the area under the curve of $s\cos\phi$ plotted against ϕ. Since $\cos\phi \cong 1$, it is usual to take the area under the s–ϕ curve.

Von Karman's Method

In this theory, the differential equation is solved assuming simple plane deformation and slipping friction, by graphical integration as in the previous theory but without the correcting factor w, the horizontal force f being assumed uniform over the height h. This method gives results which, for cold rolling, differ only very slightly from Orowan's general theory. No comparison, therefore, has been made for this theory ; the calculations involved are extremely laborious.

Siebel's Friction-Hill Theory

This theory makes several approximations in addition to those made in the 'homogeneous-graphical' method. These approximations are :

(i) The normal roll pressure s is equated to the mean yield stress $\bar{k}$ in the differential equation for s, but not after the equation has been solved

(ii) The normal roll pressure is considered equal to the vertical pressure

(iii) The yield stress k is assumed constant throughout the arc of contact and, in what follows, will be taken as the mean yield stress $\bar{k}$.

Siebel did not consider the effect of roll flattening, and used the roll radius R in his equations ; where appropriate, the authors have replaced R by R', the radius of the flattened arc. Siebel and his collaborators have indicated that this theory can be made to cover tension rolling, but they have not developed expressions for roll force and torque for this case. It is, however, possible to do so, and the authors have developed the necessary equations so that all the possible methods can be compared. The calculation is given in Appendix II.

Tselikov's Method

Tselikov made many assumptions in obtaining his expression for roll force. His equations have been dealt with in detail by Underwood.[10]

At any point in the roll gap where the strip has thickness h, the roll pressure is given by :

$$s = \frac{\bar{k}}{(1 + \mu\tan\tfrac{1}{2}\phi_1)(1 + \xi)}\left\{\left[\left(1 - \frac{\sigma_1}{\bar{k}}\right)(1 + \xi) - 1\right]\left(\frac{h_1}{h}\right)^{1+\xi} + 1\right\} \quad \ldots\ldots(13)$$

from entry to the neutral point,* and :

$$s = \frac{\bar{k}}{(1 - \mu\tan\tfrac{1}{2}\phi_1)(\eta - 1)}\left\{\left[\left(1 - \frac{\sigma_2}{\bar{k}}\right)(\eta - 1) + 1\right]\left(\frac{h}{h_2}\right)^{\eta - 1} - 1\right\} \quad \ldots\ldots(14)$$

from exit to the neutral point,* where ξ and η are given by :

$$\xi = \frac{\tan(\alpha - \tfrac{1}{2}\phi_1)}{\tan\tfrac{1}{2}\phi_1}, \quad \eta = \frac{\tan(\alpha + \tfrac{1}{2}\phi_1)}{\tan\tfrac{1}{2}\phi_1}.$$

The neutral point is given by :

$$\frac{h_n}{h_2} = \left\{\frac{1 + \sqrt{\left[1 + \left(\frac{\bar{k} - \sigma_1}{\bar{k}} - 1\right)\left(\frac{\bar{k} - \sigma_2}{\bar{k}} + 1\right)\left(\frac{h_1}{h_2}\right)^{\gamma}\right]}}{\left(\frac{\bar{k} - \sigma_2}{\bar{k}} \cdot \gamma + 1\right)}\right\}^{\frac{1}{\gamma}} \quad \ldots(15)$$

where $\gamma = \dfrac{\mu}{\tan\frac{1}{2}\phi_1}$ and $\alpha = \tan^{-1}\mu$.

Tselikov also gives an expression for roll force as follows :

$$P = \frac{\bar{k}\, h_n \tan\tfrac{1}{2}\phi_1 \sqrt{R'(h_1 - h_2)}}{(h_1 - h_2)}\left[\left(\frac{1}{\gamma - 1}\right)\left\{\left(1 - \frac{\sigma_1}{\bar{k}}\right) - 1\right\}\left\{\left(\frac{h_1}{h_2}\right)^{\gamma} - \left(\frac{h_1}{h_n}\right)\right\} + \left(\frac{h_1}{h_n} - 1\right) + \left(\frac{1}{\gamma + 1}\right)\left\{\left(1 - \frac{\sigma_2}{\bar{k}}\right) + 1\right\}\left\{\left(\frac{h_n}{h_2}\right)^{\gamma} - \left(\frac{h_2}{h_n}\right)\right\} - \left(1 - \frac{h_2}{h_n}\right)\right] \quad \ldots\ldots(16)$$

The expressions are cumbersome to use.

* It can easily be shown that Tselikov's constant terms $\dfrac{1}{(1 + \mu\tan\frac{1}{2}\phi_1)(1 + \xi)}$ and $\dfrac{1}{(1 - \mu\tan\frac{1}{2}\phi_1)(\eta - 1)}$ are identical and are equal to $\dfrac{\tan\frac{1}{2}\phi_1}{\mu(1 + \tan^2\frac{1}{2}\phi)_1}$.

Nádai's Equations for Roll Force

Nádai[8] derived an expression for roll force by integrating the normal roll pressure over the arc of contact.

From exit to the neutral point, the normal roll pressure is given by :

$$s = \bar{k}\left[\left\{\left(1 - \frac{\sigma_2}{\bar{k}}\right) + \frac{h_2}{2\mu^2 R'}\right\}e^{\mu H} - \frac{h_2}{2\mu^2 R'}(1 + \mu H)\right] \quad \ldots(17)$$

and from entry to the neutral point, the normal roll pressure is given by :

$$s = \bar{k}\left[\left\{\left(1 - \frac{\sigma_1}{\bar{k}}\right) + \frac{h_2}{2\mu^2 R'}(1 - \mu H_1)\right\}e^{\mu(H_1 - H)} - \frac{h_2}{2\mu^2 R'}(1 - \mu H)\right] \quad \ldots(18)$$

Hill's Non-Dimensional Presentation of Cold-Rolling Data

Hill has shown that, for the experimental results obtained on the Sheffield experimental mill, a correlation exists between the non-dimensional group $\dfrac{G}{PR}$ and the group $\dfrac{\sigma_2 h_2 - \sigma_1 h_1}{P}$, for a given angle of contact.

Figure 10 shows the mean line through Hill's experimental points for an angle of contact of $\phi_1 = 0{\cdot}0655$ radians. The correlation should hold irrespective of the yield stress and, accordingly, of first or subsequent passes. Since these results of Hill's are the only experimental figures available, it was decided to compare the various theories for a contact angle of $\phi_1 = 0{\cdot}0655$ radians, on strip 0·0635 in. thick, rolled in a mill with 10-in. dia. rolls, as in the actual experiments. Hill's method allows him to estimate the coefficient of friction, and he gives $\mu = 0{\cdot}063$ for

Table I

COMPARISON OF VALUES OF ROLL FORCE AND TORQUE CALCULATED BY VARIOUS THEORIES

Tensions		Dimensions, in.						Deformed Roll Radius R', in.				Mean Yield Stress $\bar{k}$	Roll Force P, tons per inch width					
				h_2														
σ_1	σ_2	h_0	h_1	Orowan	Bland and Ford	Bland and Ford Curves	Nádai	Orowan	Bland and Ford	Bland and Ford Curves	Nádai		Orowan	Bland and Ford	Bland and Ford Curves	Nádai	Siebel	Tselikov
5·09	0	0·0635	0·0635	0·0383	0·0393	0·0382	0·0383	5·89	5·65	5·90	5·88	37·7	13·9	9·9	14·1	14·1	13·3	15·3
3·0	0	0·0635	0·0635	0·0379	0·0380	0·0378	0·0378	5·96	5·84	6·00	6·00	37·7	15·1	12·7	15·5	15·5	15·4	16·6
1·0	0	0·0635	0·0635	0·0377	0·0378	0·0377	..	6·04	6·00	6·03	..	37·7	16·4	15·8	16·2	..	16·2	..
0	0	0·0635	0·0635	0·0374	0·0375	0·0375	0·0374	6·10	6·08	6·08	6·10	37·7	17·2	17·2	16·9	17·1	16·8	18·4
0	4·0	0·0635	0·0635	0·0375	0·0375	0·0375	..	6·06	6·06	6·06	..	37·7	16·8	16·8	16·3	..	16·8	17·7
0	10·0	0·0635	0·0635	0·0379	0·0379	0·0379	..	5·98	5·98	5·98	..	37·7	15·4	15·4	15·1	..	15·9	..
0	18·0	0·0635	0·0635	0·0383	0·0383	0·0383	0·0383	5·88	5·88	5·88	5·89	37·7	13·6	13·6	13·1	13·2	13·9	12·9
3·0	12·0	0·0635	0·0635	0·0383	0·0387	0·0383	..	5·88	5·78	5·88	..	37·7	13·4	11·9	13·5	..	12·6	..
7·0	16·0	0·0635	0·0635	0·0387	0·0399	0·0387	0·0387	5·78	5·50	5·78	5·78	37·7	11·3	7·0	11·8	11·2	11·7	12·7
10·0	0	0·0635	0·0535	0·0282	0·0278	0·0278	0·0278	5·90	5·97	6·00	5·97	43·3	14·1	15·3	15·9	15·3	15·0	17·0
0	0	0·0635	0·0535	0·0265	0·0265	0·0265	0·0265	6·30	6·30	6·30	6·31	43·3	21·0	21·0	20·8	21·9	20·7	23·2
0	18·0	0·0635	0·0535	0·0274	0·0274	0·0274	0·0273	6·10	6·10	6·10	6·12	43·3	17·7	17·7	17·3	18·1	18·0	17·2

these tests. This value has accordingly been used in the comparison of the various theories.

COMPARISON OF VALUES OF ROLL FORCE AND TORQUE CALCULATED BY VARIOUS THEORIES

In Fig. 10 the values of the two groups $\frac{G}{PR}$ and $\frac{\sigma_2 h_2 - \sigma_1 h_1}{P}$ for each of the theories examined (except for Tselikov, who gives no torque equation) are given, over the practical range of tensions, in first passes and second passes, for an angle of contact of 0·0655 radians.

The full details of the calculated results are given in Table I. Each pass was calculated and recalculated until the values of the roll force P, and the radius of the contact arc R', were consistent with each other on the basis of Hitchcock's formula :

$$R' = R\left(1 + \frac{2cP}{h_1 - h_2}\right),$$

where c is a constant relating to the elastic constants of the material of the roll, and is equal to $1{\cdot}67 \times 10^{-4}$ inch and ton units.

The results are considered according to whether the theories allow for a varying yield stress or are limited to a constant yield stress. Theories of Orowan, Bland and Ford, and (in one case) Nádai, are compared using a varying yield stress, and theories of Bland and Ford (by means of the non-dimensional curves of Figs. 2–5), Nádai, Siebel, and Tselikov, are compared using constant yield stress. The theories are then compared generally.

Variable Yield Stress

Figure 11, which shows all the passes investigated, was obtained by using a stepwise numerical solution with the yield-stress curve of Fig. 9. The comparison between Orowan's general theory and the Bland and Ford approximate method is clearly illustrated ; the agreement is good in all cases except for first passes with a high back tension, for which the approximate method gives a much lower roll force. Thus, in Fig. 11*a*, Orowan gives $P = 13{\cdot}9$ tons/in., whereas $P = 9{\cdot}9$ tons/in. for the approximate method. This pass represents, for the given angle of contact and according to the Bland and Ford method, the highest back tension that can be applied alone without slipping occurring. Figures 11*b* and 11*c* show the progressive improvement in the agreement as the back tension is reduced. The effect is not so marked in the second passes : Fig. 11*j* has a high back tension (10 tons/sq. in.) and no front tension, and the values of roll force are 14·1 and 15·3 tons per inch width for the general theory and approximate theory, respectively. On first passes, however, even when there is a front tension as well as a back tension, the effect is very marked, as will be seen from Figs. 11*h* and *i*.

This discrepancy is caused by the approximations made in the Bland and Ford method, but its nature is not yet understood. In several cases, however, comparison with experiment shows that Orowan's value of roll force is frequently as much in excess of the experimental figure as the Bland and Ford value is below.

In practice, it is seldom that a high back tension can be applied to a coil of strip in the annealed or

Table I—*continued*

Roll Torque G, tons-in. per inch width					Hill's Correlation									
					$\frac{G}{PR}$					$\frac{\sigma_2 h_2 - \sigma_1 h_1}{P}$				
Orowan	Bland and Ford	Bland and Ford Curves	Nádai	Siebel	Orowan	Bland and Ford	Bland and Ford Curves	Nádai	Siebel	Orowan	Bland and Ford	Bland and Ford Curves	Nádai	Siebel
2·71	2·12	2·91	2·90	2·81	0·0392	0·0429	0·0412	0·0425	0·0425	−0·0232	−0·0326	−0·0228	−0·0236	−0·0234
2·59	2·22	2·87	2·87	2·86	0·0344	0·0352	0·0372	0·0372	0·0373	−0·0126	−0·0150	−0·0123	−0·0123	−0·0124
2·48	2·36	2·68	..	2·77	0·0304	0·0300	0·0332	..	0·0344	−0·0039	−0·0040	−0·0039	..	−0·0039
2·44	2·44	2·65	2·68	2·67	0·0285	0·0285	0·0315	0·0314	0·0319	0	0	0	0	0
2·07	2·07	2·23	..	2·12	0·0247	0·0247	0·0275	..	0·0253	0·0089	0·0089	0·0092	..	0·0089
1·38	1·38	1·55	..	1·26	0·0180	0·0180	0·0206	..	0·0159	0·0247	0·0247	0·0249	..	0·0236
0·37	0·37	0·61	0·63	0·23	0·0055	0·0055	0·0094	0·0094	0·0033	0·0506	0·0506	0·0525	0·0521	0·0495
1·32	1·06	1·56	..	1·43	0·0198	0·0178	0·0232	..	0·0228	0·0200	0·0230	0·0199	..	0·0213
1·20	0·47	1·36	1·36	1·37	0·0213	0·0135	0·0232	0·0244	0·0236	0·0155	0·0292	0·0148	0·0156	0·0150
3·33	3·46	3·69	..	3·53	0·0475	0·0455	0·0466	..	0·0473	−0·0379	−0·0350	−0·0336	..	−0·0356
3·16	3·16	3·24	..	3·17	0·0302	0·0292	0·0313	..	0·0308	0	0	0	..	0
1·66	1·66	1·73	..	1·55	0·0189	0·0189	0·0201	..	0·0173	0·0279	0·0279	0·0285	..	0·0274

the hot-rolled condition: a tension cannot conveniently be applied until the strip has been once through a mill stand, and the discrepancy in the values of roll force does not occur in calculations relating to practical examples. In any case, until more experimental results are available it is not possible to say whether Orowan's general theory gives more reliable values of the roll force than does the approximate method.

Nádai's equations were used with a variable yield-stress by evaluating the normal roll pressure s from point to point, as in the two methods already discussed. Figure 12 shows the result for the first pass with high back tension; the curve is further away

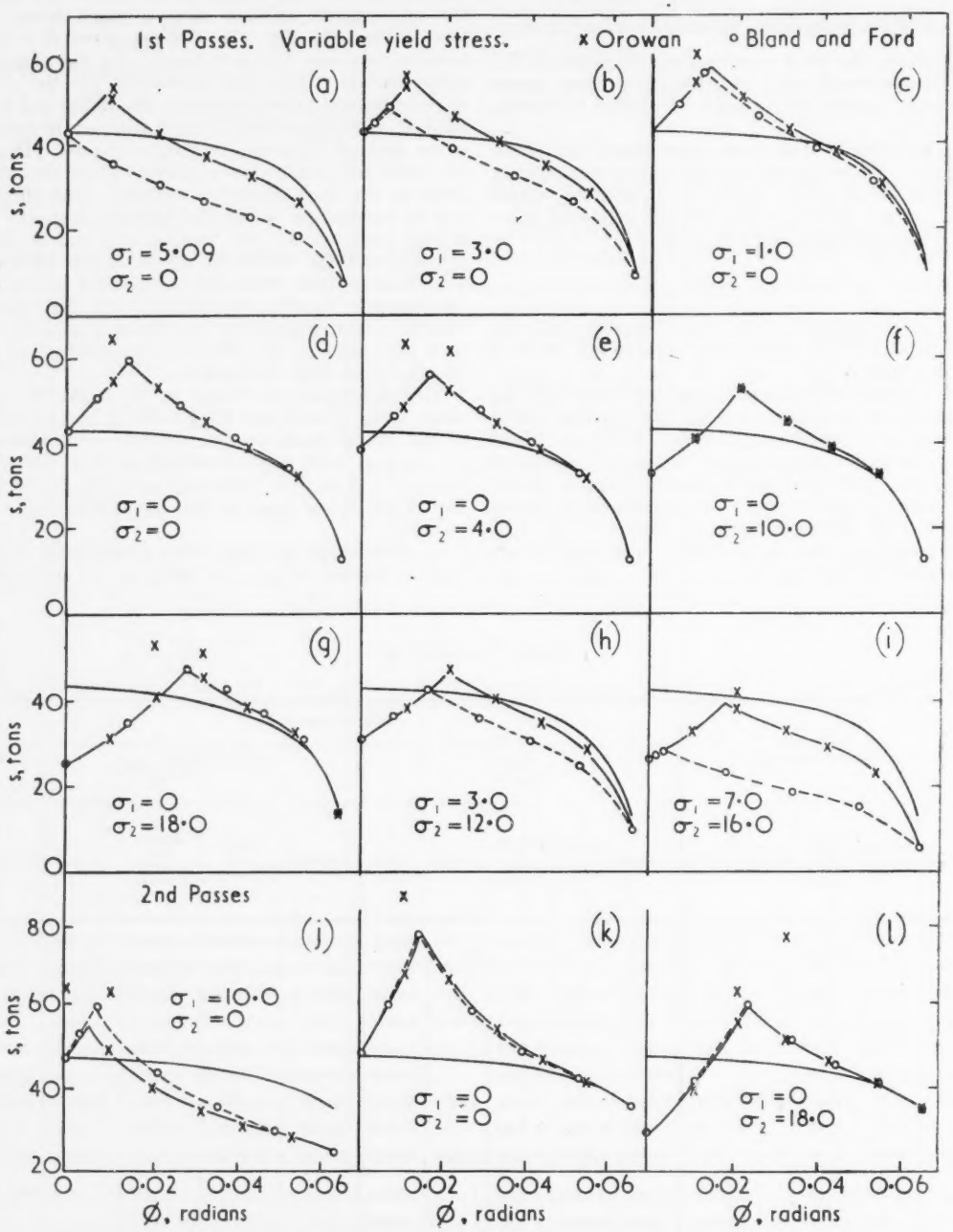

Fig. 11—Values of roll force, obtained with variable yield-stress, showing comparison between Orowan's general theory and Bland and Ford's approximate method

than that for the method of Bland and Ford, and it was decided to discontinue the calculations.

Mean Yield Stress

The mean yield stress for the first passes was calculated by the method outlined on p. 64, and was found to be 37·7 tons/sq. in. For the second passes it was 43·3 tons/sq. in. Figure 13 shows the same passes as in Fig. 11, but using the mean yield-stress values, and Table I shows at once the corresponding values of total roll force and torque. Table I gives also the roll force and torque for the Orowan

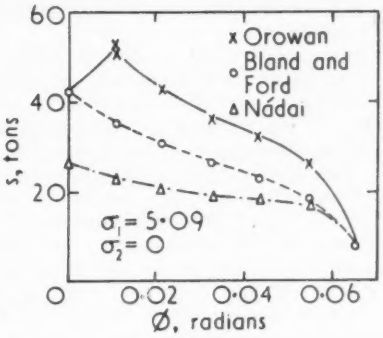

Fig. 12—Values of roll force, obtained with variable yield-stress, from Nádai's equations

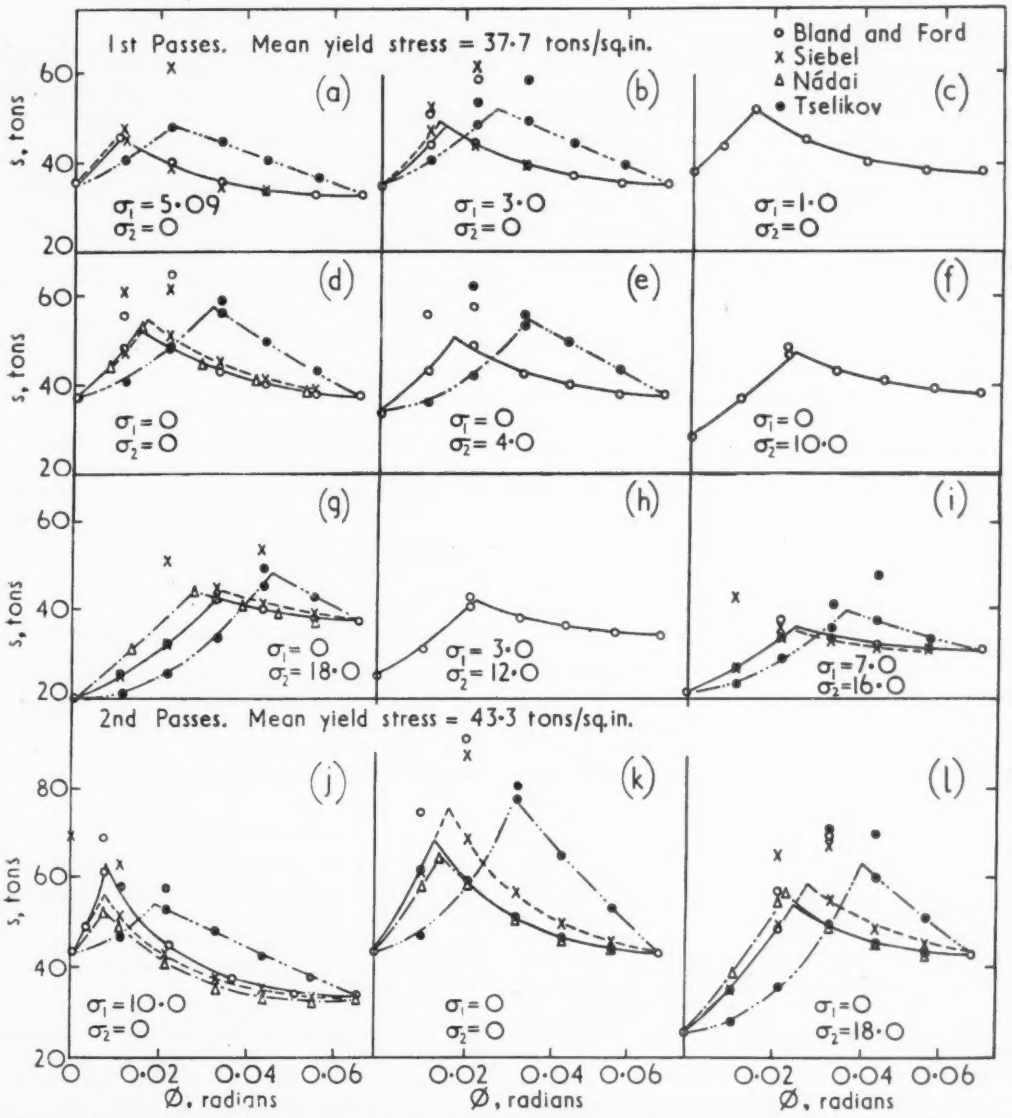

Fig. 13—Values of roll force, obtained with mean yield-stress, showing comparison between the various theories

method, and for the Bland and Ford method using a variable yield stress.

Tselikov's method gives a sharply peaked distribution, the neutral point being very much nearer to the entry than it is for the other theories. The roll force given by this method is generally higher than for any of the other theories, but is occasionally less. Tselikov gives no formula for roll torque, and as his method apparently has no advantages over the other methods, the torque expression previously developed[2] (*see* equation (4)) was not applied; accordingly, no torque values are given for Tselikov in Table I.

The results for the Bland and Ford method are given for constant yield stress. (Note that the area under the appropriate diagram is the roll force given by the curves developed in this paper.) Comparing these with the results obtained by Nádai's equation, it will be seen that Nádai's values are generally slightly higher, except when there is a high back tension. This is in agreement with the results shown in Fig. 12 for variable yield stress. On the other hand, Siebel's method—as would be expected from the approximations made—gives very slightly lower values of roll pressure, except where the friction hill is small, when all three methods give almost identical results. The neutral point is negligibly affected with these three theories.

General Comparison

The general comparison is more easily made from Table I, which shows all the results. The values of roll force P for Orowan and for Bland and Ford, obtained with varying yield stress, show the effect of high back tension on the latter theory, and the close agreement at all other points. On the other hand, when a mean yield stress and the non-dimensional curves are used, there is very good agreement over the whole range, even for high back tension. Nádai's results are only negligibly different from those found from the curves. Tselikov's values are generally higher, and in most cases the roll force obtained by means of equation (16) did not agree with the area under the curve of roll pressure found from equations (13) and (14).

The agreement between values of roll torque obtained by Orowan's method and by the Bland and Ford method, for varying k, is good when the roll-force agreement is good, and vice versa. The curves again give values nearer to the Orowan results; Nádai's equation for roll force was used in equation (4) to give torque values, which are in good agreement with the values from the curves. The Siebel values, also, closely follow the other results, although slightly underestimating the effect of both high back and high front tensions.

These results were then arranged in the non-dimensional groups proposed by Hill, and Fig. 10 shows all the calculated data compared with the appropriate experimental line of Hill. The points found from Orowan's theory lie almost exactly on the experimental line, for both back and front tension, as also do those for the Bland and Ford method with variable yield stress. In some cases the individual values of P and G are very different for the two theories, and therefore it can be concluded that, within wide limits, Hill's method of plotting is insensitive to the numerical results.

The points obtained from the curves are slightly high, but they all lie on a line running parallel with the experimental line. For this method the second passes give points lying on the same line, whereas with Orowan's method the points tend to be rather higher than those for first passes. As expected, Nádai's method gives points agreeing with those found from the non-dimensional curves. There is some scatter of the Siebel points, and the slope of the curve when front tension predominates is a little different from that when back tension predominates.

CONCLUSIONS

The non-dimensional curves developed in this paper, for cold strip rolling with tension, give results for roll force and torque in good agreement with those obtained for comparable passes by Orowan's general theory, and also with those from other available theories. The integration of Siebel's differential equation shows that the additional approximations made by Siebel do not lead to any serious errors in cold rolling, where the friction hill is generally small. The resulting expressions for roll force and torque are, however, more cumbersome, and take much longer to use than the curves.

Of the other methods, Nádai's equation for roll pressure gives values closely agreeing with the curves, although it does not appear to be very accurate when a variable yield-stress curve is used. No equation for roll torque was evolved by Nádai, but equation (4) can be used to evaluate torque. The method takes much longer to work out for practical cases, because the pressure distribution has to be calculated, from which the roll force is found by graphical integration.

Tselikov's equations give pressure distributions essentially different from those given by all the other theories. The equations are difficult to use, and no equation for roll torque is available.

In comparison with the experimental results quoted by Hill, the curves give points lying slightly above the experimental points, but the difference is not great and the trend is the same. It is not possible at this stage to show how the calculated results compare with individual experimental readings, since the Sheffield measurements have not yet been published.

Acknowledgments

The award of a Carnegie Research Grant to one of the authors (H.F.) allowed the calculations of the functions f_3 and f_5 to be carried out. Without this help the paper could not have been written, and the authors wish to place on record their gratitude to the Carnegie Grants Committee.

They also wish to express their appreciation of the help given to them by the staff of the Mechanical Working Division of the British Iron and Steel Research Association; and, in particular, by Mr. W. C. F. Hessenberg and Mr. R. B. Sims.

The authors thank Mr. A. B. Watts for determining the yield-stress curve for the mild-steel samples.

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APPENDIX I

Derivation of the Functions f_3 and f_5

The Roll Force Function f_3

Inserting the values of s^+ and s^- into equation (3) gives :

$$P = R'\bar{k}\left[\int_0^{\phi_n}\frac{h}{h_2}\left(1-\frac{\sigma_2}{\bar{k}}\right)e^{\mu H}d\phi+\int_{\phi_n}^{\phi_1}\frac{h}{h_1}\left(1-\frac{\sigma_1}{\bar{k}}\right)e^{\mu(H_1-H)}d\phi\right] \quad \ldots(3a)$$

Change the dependent variables as follows :

$$a=\mu\sqrt{\frac{R'}{h_2}}\;;\; b=\frac{1-\frac{\sigma_2}{\bar{k}}}{1-\frac{\sigma_1}{\bar{k}}}\;;\; r=\frac{h_1-h_2}{h_1}.$$

For ease in calculation, put $x=\sqrt{\frac{R'}{h_2}}\,\phi$,

$$i.e., dx=\sqrt{\frac{R'}{h_2}}\,d\phi.$$

Then :

$$\frac{h}{h_2}=\frac{h_2+R'\phi^2}{h_2}=1+x^2$$

$$\text{and } \frac{h}{h_1}=\frac{h_2}{h_1}\cdot\frac{h_1}{h_2}=(1-r)(1+x^2).$$

Also, $\mu H = 2a\tan^{-1}x$, and $\mu H_1 = 2a\tan^{-1}x_1$.

Equation (3a) thus becomes :

$$\begin{aligned}P &= R'\bar{k}\left(1-\frac{\sigma_1}{\bar{k}}\right)\left[\int_0^{x_n}b(1+x^2)\,e^{2a\tan^{-1}x}\sqrt{\frac{h_2}{R'}}\,.\,dx\right.\\&\quad\left.+\int_{x_n}^{x_1}(1-r)(1+x^2)\,e^{2a\tan^{-1}x_1}\sqrt{\frac{h_2}{R'}}\,.\,dx\right]\\&=\bar{k}\left(1-\frac{\sigma_1}{\bar{k}}\right)\sqrt{R'(h_1-h_2)}\left[\sqrt{\frac{1-r}{r}}\right.\\&\quad\int_0^{x_n}b(1+x^2)\,e^{2a\tan^{-1}x}dx\\&\quad\left.+(1-r)\sqrt{\frac{1-r}{r}}e^{2a\tan^{-1}x_1}\int_{x_n}^{x_1}(1+x^2)\,e^{-2a\tan^{-1}x}dx\right]\\&=\bar{k}\left(1-\frac{\sigma_1}{\bar{k}}\right)\sqrt{R'(h_1-h_2)}\,f_3(a,r,b)\quad\ldots\ldots(6)\end{aligned}$$

The quantity within the square brackets, indicated by f_3 in equation (6), need be calculated only once for the whole practical range of r, a, and b. The equations governing the range of these values are :

(i) For any pass :

$$x_1=\sqrt{\frac{r}{1-r}}$$

$$x_n=\tan\left[\tfrac{1}{2}\tan^{-1}\sqrt{\frac{r}{1-r}}-\frac{B}{4a}-\frac{\log_e(1-r)}{4a}\right]\quad\ldots(19)$$

where $B=\log_e b$.

(ii) When the front tension is so high that the neutral point moves to entry, then $x_n = x_1$.

$$\therefore\quad a=\frac{\log_e(1-r)-B}{2\tan^{-1}\sqrt{\frac{r}{1-r}}}\quad\ldots\ldots\ldots\ldots(20)$$

(iii) When the back tension is so high that the neutral point moves to exit, then $x_n = 0$.

$$\therefore\quad a=\frac{B-\log_e(1-r)}{2\tan^{-1}\sqrt{\frac{r}{1-r}}}\quad\ldots\ldots\ldots\ldots(21)$$

From equations (19)–(21) it is possible to calculate the limiting values of r for given values of a and B.

The Roll Torque Function f_5

Inserting the values of s^+ and s^- into equation (4) gives :

$$\begin{aligned}G &= RR'\bar{k}\left(1-\frac{\sigma_1}{\bar{k}}\right)\left[\int_0^{\phi_n}\frac{h}{h_2}be^{\mu H}\phi d\phi\right.\\&\quad\left.+\int_{\phi_n}^{\phi_1}\frac{h}{h_1}e^{\mu(H_1-H)}\phi d\phi\right]\quad\ldots(4a)\\&=R\bar{k}\left(1-\frac{\sigma_1}{\bar{k}}\right)\left[h_2\left\{b\int_0^{x_n}(1+x^2)xe^{2a\tan^{-1}x}dx\right.\right.\\&\quad\left.\left.+(1-r)e^{2a\tan^{-1}x_1}\int_{x_n}^{x_1}(1+x^2)xe^{-2a\tan^{-1}x}dx\right\}\right]\\&=R\bar{k}(h_1-h_2)\left(1-\frac{\sigma_1}{\bar{k}}\right)f_5(a,r,b)\quad\ldots\ldots\ldots\ldots(7)\end{aligned}$$

The expression inside the square brackets, given by function f_5 in equation (7), can be worked out over the practical range for cold rolling, as for the roll force expression.

APPENDIX II

Development of Siebel's Friction Hill Theory for Roll Force and Torque, with and without Tensions

Siebel considers any point A (Fig. 1) in the arc of contact at angle ϕ, in terms of its horizontal co-ordinate x from the exit plane. As in previous work, the roll radius R in Siebel's theory will be replaced where appropriate by R', the radius of the flattened arc. Unit width of strip will be considered and, to be consistent with other papers, the co-ordinate x will be replaced by $R'\phi$, and the equations developed in terms of the angular co-ordinate ϕ.

It can be shown that Siebel's method gives an equation for the total horizontal force f, at ordinate ϕ, as follows :

$$f=2\bar{k}R'\int_0^{\phi}(\phi\pm\mu)d\phi+C',$$

where C' is a constant of integration. If ϕ_n is the co-ordinate of the neutral plane, and if ϕ is defined by :

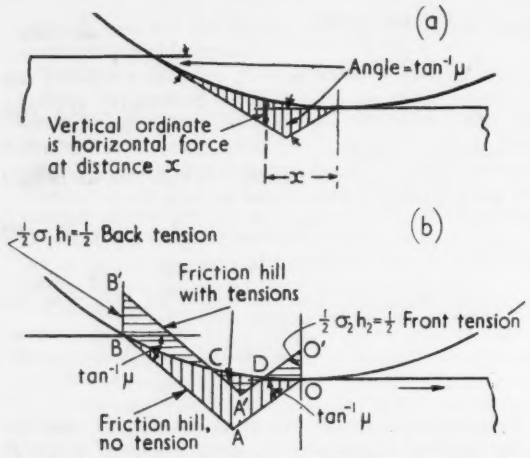


Fig. 14—Graphical form of equation (22), according to Siebel, showing effect of rolling with tension

$$\Phi = \begin{cases} \phi \text{ for } \phi < \phi_n \\ \phi_n \text{ for } \phi \geqslant \phi_n \end{cases}$$

then:

$$f = C' + \bar{k}R'\phi^2 + 2\bar{k}R'\mu\Phi - 2\bar{k}R'\mu(\phi - \Phi)$$
$$= C' + \bar{k}R'\phi^2 + 2\bar{k}R'\mu(2\Phi - \phi) \quad \ldots\ldots\ldots\ldots\ldots(22)$$

Siebel points out that these relationships can be represented graphically by setting off, at the points of entry and exit, lines inclined to the horizontal at angles $\tan^{-1}\mu$ (*see* Fig. 14*a*). The ordinates of the area between the two straight lines and the roll surface will represent the horizontal force at the roll surface, per unit width, for a resistance to deformation equal to unity (*i.e.*, $\bar{k} = 1$).

If it is now assumed that plane sections remain plane (homogeneous compression), then the horizontal force can be expressed as the horizontal stress p in the material, at section height h; *i.e.*, $p = f/h$.

The condition of plasticity gives:

$$s = p + \bar{k}$$
$$= \bar{k} + \frac{C'}{h} + \frac{\bar{k}}{h} R'\phi^2 + \frac{2\bar{k}R'}{h}\mu(2\Phi - \phi) \quad \ldots\ldots(23)$$

Replace C' by $(C + \bar{k}h_2)$ and h by $h_2 + R'\phi^2$.

Then: $s = 2\bar{k} + \dfrac{C}{h} + \dfrac{2\bar{k}R'\mu}{h}(2\Phi - \phi) \quad \ldots\ldots\ldots\ldots(24)$

Boundary Conditions and Neutral Angle for Rolling with Tension

The effect of tension is seen clearly in Siebel's graphical representation (Fig. 14*b*). The lines BA and OA are set off for the same data, but without tension, the lines being sloped as before at the angle of friction; then the vertically hatched area OAB between these lines and the roll surface is the (positive) horizontal force. If distances $OO' = \frac{1}{2}\sigma_2 h_2$ (half the front tension per unit width) and $BB' = \frac{1}{2}\sigma_1 h_1$ (half the back tension per unit width) are now set off vertically from the points O and B, respectively, two new lines $O'A'$ and $B'A'$ can be drawn at the friction angle (*i.e.*, parallel to OA and BA), and the cross-hatched areas then represent the horizontal force. The areas $O'OD$ and $B'BC$, which are above the roll surface in Fig. 14*b*, are to be considered negative, and the friction hill is reduced by these amounts. To calculate any value of the normal roll pressure s, it is necessary to find ϕ_n, the co-ordinate of the neutral point. When $\phi = 0$, $p_2 = -f_2/h_2 = -\sigma_2$, and when $\phi = \phi_1$, $p_1 = -f_1/h_1 = -\sigma_1$. Therefore, at exit, $s_2 = p_2 + \bar{k} = \bar{k} - \sigma_2$. Substituting these values in equation (24) gives:

$$\bar{k} - \sigma_2 = 2\bar{k} + \frac{C}{h_2}$$

i.e., $C = -h_2(\bar{k} + \sigma_2)$.

Equation (24) can now be written:

$$s = 2\bar{k} - \frac{h_2(\bar{k} + \sigma_2)}{h} + \frac{2\bar{k}R'\mu(2\Phi - \phi)}{h} \quad \ldots\ldots(25)$$

At entry, $s_1 = p_1 + \bar{k} = \bar{k} - \sigma_1$.

$$\therefore \bar{k} - \sigma_1 = 2\bar{k} - \frac{h_2(\bar{k} + \sigma_2)}{h_1} + \frac{2\bar{k}R'\mu(2\phi_n - \phi_1)}{h_1},$$

and, rearranging:

$$\phi_n = \frac{\phi_1}{2} - \frac{1}{4\bar{k}R'\mu}(\delta\bar{k} + h_1\sigma_1 - h_2\sigma_2) \quad \ldots\ldots(26)$$

where $\delta = h_1 - h_2$. When no tensions are applied, $\sigma_1 = \sigma_2 = 0$; substituting $R'\phi_1^2$ for δ in equation (26):

$$\phi_n = \frac{\phi_1}{2} - \frac{1}{2\mu}\phi_1^2.$$

Roll Force

The roll force P per unit width is given by:

$$P = R'\int_0^{\phi_1} s\,d\phi.$$

Substituting for s from equation (24), and integrating:

$$P = 2\bar{k}\sqrt{R'\delta} - \sqrt{R'h_2}(\bar{k} + \sigma_2)\tan^{-1}\sqrt{\frac{\delta}{h_2}}$$
$$+ \bar{k}\mu R'\log_e\left(\frac{h_n^2}{h_1h_2}\right) + 4\bar{k}\mu\phi_n R'\sqrt{\frac{R'}{h_2}}\left\{\tan^{-1}\sqrt{\frac{\delta}{h_2}}\right.$$
$$\left. - \tan^{-1}\sqrt{\frac{R'}{h_2}}\cdot\phi_n\right\} \ldots(27)$$

Roll Torque

The torque G per roll per unit width is given by the expression:

$$G = RR'\left[\int_0^{\phi_1} s\phi d\phi + \frac{\sigma_1h_1 - \sigma_2h_2}{2R'}\right].$$

Using equations (4) and (24), and integrating, gives:

$$G = \frac{R}{2}(\sigma_1h_1 - \sigma_2h_2) + \bar{k}R'\delta - \frac{R'}{2}h_2(\bar{k} + \sigma_2)\log_e\frac{h_1}{h_2}$$
$$+ 2\bar{k}R'\mu(2\phi_n - \phi_1) + 2\bar{k}\mu\sqrt{R'h_2}\left\{\tan^{-1}\sqrt{\frac{\delta}{h_2}}\right.$$
$$\left. - 2\tan^{-1}\sqrt{\frac{R'}{h_2}}\cdot\phi_n\right\} + 4\bar{k}R'\mu\phi_n\log_e\frac{h_1}{h_2} \ldots(28)$$

Forward Slip

The forward slip m is defined by:

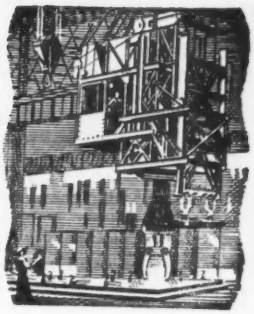
$$m = \frac{h_n\cos\phi_n - h_2}{h_2}$$
$$\simeq \frac{h_n - h_2}{h_2} = \frac{R'}{h_2}\phi_n^2.$$

$$\therefore \phi_n = \sqrt{\frac{mh_2}{R'}} = \frac{\phi_1}{2} - \frac{1}{4\bar{k}R'\mu}(\delta\bar{k} + \sigma_1h_1 - \sigma_2h_2).$$

When there are no strip tensions, *i.e.*, $\sigma_1 = \sigma_2 = 0$, the forward slip is given by:

$$m = \frac{R'}{h_2}\left(\frac{\phi_1}{2} - \frac{\phi_1^2}{4\mu}\right)^2.$$

IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE THIRTEENTH MEETING

THE THIRTEENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 28th June, 1950. Mr. C. H. T. Williams, Chairman of the Group, was in the Chair.

The MORNING SESSION was devoted to the presentation and discussion of the two papers: "Heating and Ventilation in the Iron and Steel Industry," by F. R. L. White (Brightside Foundry and Engineering Co., Ltd.), and "Lighting in Iron and Steel Works," by G. W. Levey (McLellan and Partners).

The AFTERNOON SESSION was devoted to the presentation and discussion of the paper: "The Supply and Distribution of Water to Iron and Steel Works," by J. L. Daniel (Stewarts and Lloyds, Ltd.). The discussion on the first paper was published in the April issue of the *Journal*. That on the second paper and on the paper by Mr. Daniel is given below.

PROCEEDINGS OF PART OF THE MORNING SESSION: 10.30 A.M. to 1.00 P.M.

Discussion on the Paper—
LIGHTING IN IRON AND STEEL WORKS*

Mr. **G. W. Levey** briefly presented his paper.

Mr. **J. L. Gaskell** (Appleby-Frodingham Steel Co.): The author states in the synopsis that his suggestions are justified by increased quantity and quality of output. Can he provide evidence in support of this statement in regard to iron and steel works? If so, it would be easier to establish a case for spending money on improved lighting; generally, there are only the indeterminate factors of better working conditions, less risk of accident, and greater incentive to keep the place tidy, in favour of better lighting.

I am pleased to see that in the table of recommended intensities for typical steelworks buildings, the exemptions to S.R. & O. 1941, No. 94, have been ignored. Twelve lumens/sq. ft. is unnecessarily high for the items in this group, excepting offices, for which I suggest that the illumination should be 15 lumens/sq. ft. or even higher, if close work is done.

I endorse the author's remarks on the satisfactory quality of light from mixed tungsten and mercury discharge lamps, though surely such drops as the 15% voltage drop to which he refers are not found with a well-designed distribution system.

Figure 1 is too cramped to show the balancing points clearly. I suggest that it should have been presented as three separate figures, one for each range of annual burning time, and with the unit cost scale in each case arranged to cover a range of 0·5*d.*–1·0*d.*/unit, which I think would include most heavy-industry electricity costs. Incidentally, it is not made clear whether the respective costs of distribution systems have been considered, in preparing Fig. 1.

Column (*a*) of Table II shows less deterioration in original reflectivity than I should have expected from four months' exposure over cogging mills and over soakers; though of course local conditions for similar items of plant vary enormously. The results indicate clearly the need for frequent and regular cleaning, and I think that the frequency of cleaning should be determined for each individual lighting installation, to obtain the optimum value from the capital and cleaning costs. The industry must devote more attention to its standards of artificial lighting than it has done in the past, and easy access to fittings, which the author mentioned, entails careful planning before a new building leaves the drawing-board stage.

In general, the maintenance of an efficient installation

* *Journal of The Iron and Steel Institute*, 1950, vol. 165, May, pp. 91–96.

depends on the availability of easy access apart from that provided by overhead cranes. Maintenance of artificial lighting from overhead cranes is suitable only in those locations where the cranes are not in continuous use, *e.g.*, a power house, and in some cases engineering shops, but even then, the operation is a hazardous one. It is also advisable, where the roof structure permits, to stagger the lighting fittings across a bay in order to minimize blocking of the lights by overhead cranes.

I do not agree entirely with the author's statement that in a mixed mercury vapour and tungsten installation the lamp centres should be close together. Provided the mercury and tungsten components each give a good distribution on the working plane, it does not matter whether they are close together or not, although in practice the most convenient method of access generally requires that they should be mounted together.

The importance of light-coloured decorations cannot be over-stressed. They increase the effectiveness of lamp lumens enormously, and help in avoiding deep shadows, overcoming the depressing 'tunnel effect' in roofs.

The author commends the 415-V., 3-phase, 4-wire system for supplying both power and lighting in outlying buildings, but fault values on low-tension systems in heavy industry are often of the order of 25 mVA., and I do not think it is advisable to subject lighting circuits to such fault values.

I endorse the author's remark that lighting justifies its own distribution system, and our own practice is to distribute our lighting-supply circuits from a 440-V., 3-wire system to local 25 kVA. and 10 kVA. transformers, stepping down to 110 V. This limits fault values on the lighting sub-circuits, and also keeps us within the terms of exemption No. 1 of the Electricity Regulations.

A separate lighting distribution system also simplifies electricity allocation, under a costing system in which energy for lighting is charged separately from energy for power.

It is advisable, where practicable, to provide emergency lighting by connecting a few lights in a bay to the supply for an adjacent bay to reduce the possibility of total black-out, though if the ordinary distribution system is reliable it is not necessary to pay a great deal of attention to emergency lighting.

In regard to outside lighting, an installation consisting of relatively few flood projectors at relatively great heights would not be as effective under fog conditions as frequent fittings mounted at a height of about 25 ft. A great deal depends on how much interference with rail and road traffic can be tolerated in foggy conditions. I think the author's remark that "one floodlight will replace at least 15 reflectors on 30-ft. poles" is rather an over-statement.

The author's recommendations for roadways appear to be generous compared with the recommendations of the Ministry of Transport,* which advises for Class A traffic routes 3000–8000 lumens/100 lin. ft. and for Class B traffic routes 600–2500 lumens/100 lin. ft. I know of a private roadway which is lit by an average of 2330 lumens/100 lin. ft. by means of 125-W. mercury discharge lamps spaced at 130–160 ft. intervals, and visibility is very good, although, of course, each case must be judged on its merits.

However much thought and capital expenditure are put into it, an installation will be of little value if maintenance is inadequate. I am quite certain that lighting maintenance must be as carefully planned as other plant maintenance if value from our installations is to be obtained.

Mr. **Levey**: One of the ways in which speed-up in production may be obtained is by reduction in the time of stoppage during breakdown. If there is good lighting and the maintenance people can see to get about quickly, there is a marked reduction in the shut-down period. Moreover, speeds of production are being increased steadily, and it is well known that if the speed of production is higher, correspondingly more light is needed for clear vision.

In regard to exemptions, I think it is important, if only from the point of view of production and of the accident rate, that steelworks should have as good lighting as other works.

The 15% voltage drop refers to a momentary drop due to surge, not to a continuous voltage drop due to overloading.

I agree that Fig. 1 could be improved, but the object of including it in the paper was to give a general picture, and distribution costs are not included because they vary so much. Relative costs are in any event very little affected by them. The first object of the tests on anodized aluminium was to see what happened to the samples, and the second, to see whether they could be cleaned after contamination. The results shown in Table II are very surprising.

The obstruction of the main lighting by cranes presents a problem. The only way to deal with it is to suspend auxiliary fittings from the crane, but it is rather inefficient to use mercury vapour lamps on D.C. cranes for mixed lighting. So far, it has been found that if sufficient lighting is installed on the crane, there is no very noticeable effect when the crane moves, apart from a slight variation in the colour of the light. As to the spacing of mercury and tungsten lamps, it is possible to get a quite pronounced colour penumbra, and I still think that they should be placed together as closely as possible. I agree that the walls of works should be light in colour, though I do not suggest that soaking-pit or similar walls could be kept so. Economical cleaning periods can only be determined by actual tests.

Mr. Gaskell referred to high-tower lighting and fog conditions. In a light fog, high-tower lighting is in some ways improved, since the fog diffuses the light, and although the illumination is much lower the shadows are softened. Unless the fog is thick enough to cause operations at ground level to be suspended entirely, its effect on the lighting is not very great. The intensity of street lighting is related to the intensities of lighting within the buildings, and when operators move from one building to another, if the buildings have a high intensity of lighting, a correspondingly high intensity is needed on the roadways. It is, however, rather dangerous to generalize.

Mr. **A. Cunnington** (Formerly Lighting Engineer, Southern Region, British Railways): I am in general agreement with the author as regards theory, but there are one or two reservations I wish to make. There are two distinct sides to exterior lighting, general illumination from the viewpoints of safety, general access to the premises, and movement over a large area, and illumination for specific tasks in the open.

Experience in connection with the lighting of large railway yards showed that the high tower was valuable because it was not necessarily confined to use with mirrored reflectors, the most economic way of illuminating specific tasks, but could also be used to give a diffused illumination of general value to the whole area.

Many years ago, while watching the effect of flares dropped from the sky, I noticed the extraordinary uniformity of general illumination over a large area when there was a very high candle-power source at a very considerable height above the ground. It is not, of course, possible to copy this in actual practice, but

* *Final Report on Street Lighting*, 1937: Ministry of Transport.

it can at least be approached by erecting high masts and suspending from them clusters of diffusing fittings, so that over a large radius from the mast there is good general safety illumination.

In an iron and steel works yard, shunting processes are carried out which are very similar to those that go on in a railway yard. Concentration from the reflecting units is extremely necessary, so that the men can see clearly the condition of the points, etc.

I confirm Mr. Levey's remarks on fog conditions. Except for intense fog, which stops operations in any case, I think the general effect on the lighting is not very serious, apart from a slight lowering of the standard of illumination. Also, meteorological reports show that, except in certain areas of the country, fog is very frequently of the overhead type: in South London, where most of our experiments were carried out, there was not once a good old-fashioned fog in which to make tests, although some overhead fogs did occur, usually at a level above 150 ft.

Much more efficient light sources are likely to be obtainable in the near future, and I look forward to the time when it will be practicable to employ the water-cooled high-pressure mercury arc. No matter how intense the candle-power, these lights do not give any objectionable glare, and I think they will be used extensively.

Much of the economy in lighting which has been practised in the past has been false. On the railways, only a fraction has been spent of the amount required to provide good lighting for movement in the yards, and for the prevention of accidents. I fully agree that maintenance, and the organization to do it, should be planned from the beginning, and that people should be employed in maintenance who take pride in keeping the installation at a high level of efficiency.

Mr. Levey: The great advantage of narrow-beam projectors is that the light can be concentrated exactly where it is wanted; in the Abbey Works, for example, the sidings are rather long and narrow, unlike the normal railway marshalling yard, and a narrow-beam light is required. Similarly, high-level diffusing units are satisfactory in a large marshalling yard, but in a narrow area they would be uneconomical in also illuminating roofs or other areas where light is not required.

Mr. P. F. Grove (John Miles and Partners (London) Ltd.): Although it is necessary to have a list of recommended intensities to act as a standard, it should be remembered that good lighting also may be achieved by the application and use of reflecting surfaces. The factors involved are partly psychological and partly a question of eliminating shadows.

I have found that a single fitting, combining mercury and tungsten lamps, is not satisfactory, nor do I like the arrangement of two fittings side by side. I think that until now, better results have been obtained when the two different light sources were spaced alternately, and combined with light-coloured painted surfaces. The horizontal mounting of the mercury lamp described by Mr. Levey is, however, the key to his design and may result in a considerable improvement. The lessening of the danger of total black-out is a point in favour of the use of tungsten and mercury, but I agree with a previous speaker that voltage drops of the order of 15% seem excessive, as modern lighting is generally operated separately from power. It was a good war-time practice to provide also a few low-power emergency lights to prevent total black-out, and this is most important where dangerous processes are taking place.

Before the war, it was required to light a modern cold-mill to what was thought then to be a high standard. There was no natural lighting, except for a strip of window on one side near the roof, and even illumination, both by day and by night, was required. A test installation was set up, consisting of 16 plain and 16 colour-corrected mercury lamps and 16 combined mercury-tungsten dual lamps. From this installation, the colour-corrected mercury lamp was chosen as giving the most pleasing light. Three pieces of information were obtained during operation; first, that the intensity of the illumination dropped by 15% in the first few months, even under clean working conditions; second, that the colour-correction of the lamps scarcely affected their operation, because the globes dropped off and left plain mercury lamps; and third, that the walls ought to have been painted a light colour. At the time the installation was planned, the cost of painting a large expanse of brickwork, which otherwise did not require it, had seemed excessive.

A second experiment was made during the war in a foundry, where a system was adopted similar to that in a machining factory in which the lighting had been installed by the author's firm. Alternate tungsten and mercury lamps were fitted, and the whole interior of the building, including the machines, was painted cream. It was thought that since the foundry had to be painted in any event, it might as well be painted in this colour. The cream paint lasted quite well and remained a lightish shade for more than two years, certainly very different from the blackness usually seen in a foundry.

In the main working bays, 400-W. plain mercury lamps were placed alternately with 750–1000-W. tungsten lamps. All the fittings had visors, which gave no trouble, and contactors were used instead of local switches, as described by Mr. Levey, with resulting economies. This installation was entirely satisfactory and is still in use, although natural lighting has been introduced during the daytime for economy, and the cream paint is now being restored. A point to be noted is the difficulty of maintaining lights when there is no crane, and the floor is obstructed by ground-handling conveyors. Lamp-lowering gear has been considered, but it does not seem to be satisfactory.

Measurements with a photometer of the average steel-mill illumination at a new iron and steel works built before the war indicated working intensities about half the recommended values given in this paper. This indicates that progress has been made, but I agree with Mr. Gaskell that in some cases the recommendations seem a little high unless they omit depreciation factors.

Mr. **L. H. Hubble** (British Thomson-Houston Co., Ltd.): It is well known that lighting in the heavy industries is insufficient, and Mr. Levey and his colleagues have fixed a standard of illumination that is by no means unusually high compared with that set for similar visual tasks in other industries. Because of exemptions, and difficulties such as the magnitude of the task which makes it appear costly to undertake, the lighting of the heavy industries has been much neglected.

In regard to the arrangement of fittings, it was formerly standard practice that mixed lighting schemes were planned independently and were then superposed on one another in staggered formation. This system costs considerably more to install than when the mercury and tungsten components are in juxtaposition, and it leads to objectionable colour shadows.

The method adopted was to combine the mercury and tungsten fittings in one framework, and the author has described a novel feature by which maintenance work can be done expeditiously in a very high ambient temperature, by using reflectors which can be removed with one hand in order to be sent for polishing to the maintenance shop.

Mr. **H. S. Allpress** (Simplex Electric Co., Ltd.) : There is a need to extend adequate lighting throughout steelworks, and I deplore some of the exemptions in the Statutory Regulations. A view is still held in some sections that a reasonable lighting intensity is actually harmful for hot-steel working. I investigated this question very thoroughly some time ago and results have been published elsewhere.* I am convinced that there is no evidence at all that the provision of a good lighting intensity is harmful.

The author refers to the use of aluminium for concentrating reflectors. I have found that other types of fittings for wide spacing, made of aluminium, also operate more efficiently than those made of vitreous enamel, since whatever shape a vitreous enamel reflector may have, the polar curve is approximately the same, and is dependent only upon the size of the opening and the relative position of the lamp.

I agree with the author's remark that direct illumination falling almost vertically upon a road surface is not an efficient way of obtaining a high road-surface brightness, and that light should fall at a reasonably oblique angle, to obtain the high background brightness against which people and vehicles appear as silhouettes. Unfortunately, I believe it is rather difficult to apply the principle to the illumination of a steelworks or of a road entry, because the polar curve of the reflection factor for road surfaces is semi-circular up to a fairly high angle of incidence, and then increases abruptly. If the author intends that full advantage of this should be taken, as is done in street lighting, I consider that dangerous conditions are likely to arise in works and roadways. People coming from a building who are not shielded by the roof of a car, or by some similar shade, must be protected from the possibility of high-intensity light dazzling their eyes ; possibly a more effective method of revealing obstructions would be to illuminate the exterior road surfaces by some form of reflectors sited as extensions of the interior lighting. Roads in works should be regarded as an industrial rather than as a street-lighting problem.

Mr. **H. Long** (Benjamin Electric, Ltd.) : Can the author give any data on the relative depreciation with open fittings and enclosed fittings ? I have received some information on this subject from the electrical engineer of a tobacco factory, in which conditions are very clean and which is air-conditioned. It was found in a new installation that the difference in depreciation after two and a half months was 23% in favour of the enclosed fittings. It is therefore important to make equipment dust-proof if it is at all practicable, even in clean conditions.

I endorse the author's point concerning the quality of lighting and the limitation which can be applied satisfactorily to lamp wattage, and I also agree that in control-room lighting it is important to have large-area sources of low brightness. In a recent installation in a B.E.A. control room, indirect lighting was used because of this.

Glare from the metal and the apparent brightness of the illumination may tend to make illumination values misleading : the author has pointed out that illumination is not the most important consideration in lighting ; it is the light which is reflected from the surfaces which the eye perceives. In iron and steel works, foundries, and all other places where hot objects are handled, the brightness of the metal contrasts with the apparent brightness of the illuminated area, making it seem of very little value. In the vicinity of furnaces, there is a very strong case for increasing the illumination to a very high level, rather than reducing it.

Mr. **G. N. Hewett** (McLellan and Partners) : There is one aspect of maintenance to which I do not think any reference has been made. In designing a system for a given intensity, the most difficult factor to assess is depreciation, because it depends in practice upon the standard of maintenance, which is beyond the designer's control. If there is good maintenance, the size of the installation, and hence its capital and power costs, as well as the cost of lamp replacement, can be reduced.

Savings effected by good maintenance, however, must be considered in relation to the cost of the maintenance. Further reliable data on costs are needed, so that a balance can be reached by cutting down the initial cost of installation.

The essential minimum of maintenance is the replacement of lamps which are burnt out. It is perhaps not sufficiently realized that the 1000-hr. life of a metal-filament lamp which is burning continuously, is only six weeks ; the majority of lamps in steelworks, therefore, must be visited once every six weeks if only for replacement. If advantage were taken of every visit to clean or change the fitting, the additional cost would be very small indeed, and the opportunity should not be missed. I suggest that this should be the lowest standard of maintenance at which to aim.

Any higher standard of routine cleaning or bulk lamp changing needs to be planned carefully. It should be graded to suit the different conditions in the different shops, and the labour force should be regulated to ensure that no time is wasted.

Information on the cost of maintenance, apart from the amount required merely to replace lamps, is needed by designers, and I hope that the relevant data will be given in future papers.

Finally, I wish to draw attention to the author's remark about the use of the photometer. I think that this instrument is the only true guide to the state of an installation ; any scheme of organized maintenance should be governed by it.

Mr. **Cunnington** : I would like to corroborate Mr. Allpress's remarks on the need for caution in applying the ordinary technique of street lighting to the roadways in works. The technique which has developed as a result of the M.O.T. Report, and which is generally adopted by Local Authorities in street lighting schemes because of their strict limitation in expenditure, has become so customary that it might be thought that there are no other ways of lighting a road.

This is not so, and it is important that engineers responsible for lighting roadways in works should be aware that special considerations, such as those mentioned by Mr. Allpress, are involved, which may make it desirable to depart radically from the orthodox treatment advocated by Mr. Levey. In street lighting, the limitations on siting of light sources are very severe, but in a works yard it should be possible to light not only the roads but also the surrounding areas efficiently, and to allow for the transition from brightly lighted workshops to the much lower illumination of the roadways, by applying a different technique.

There may well be a point in favour of lighting from a high altitude to avoid distracting glare on roads.

Mr. **Levey** : In further reply to Mr. Gaskell, the fault energy on a lighting system is usually limited to a value well below 25 mVA. by the impedance of transformers and cables, and faults can be dealt with quickly and safely by high-rupturing capacity fuses. Rewirable fuses are undesirable in a modern installation, particularly as fuses to B.S. 88, categories 250 AC3 and 400

*H. S. Allpress, *Transactions of the Illuminating Engineers' Society, (London)*, 1946, vol. 11, No. 5, pp. 73–103.

AC4, are inexpensive, and so suitable for final subcircuits.

I agree with Mr. Grove that although it is convenient to classify lighting installations by intensity of illumination, this should be supplemented by proper control of shadows, of glare, and where possible, of reflectivity of surrounding surfaces, for good lighting. The importance of the quality of lighting increases with the intensity. Mr. Grove's experience with fou[r] lighting is interesting, and it is encouraging to hea[r] the light colour paint proved to be so durable.

It was not possible during the war to develop special fittings, and the best possible use of standard equipment had to be made : as Mr. Hubble confirms, widely spaced fittings cause disturbing colour shadows, which are reduced by using combined units. Lighting intensities should be limited only by installation and running costs, and the figures given in the paper are recommended as economical average values to be maintained in works, *i.e.*, not subject to depreciation factors. Mr. Allpress mentions the effect of good lighting on the observation of hot metal. I do not think the view that such observations are adversely affected by high-intensity lighting is still held, and as Mr. Long rightly points out, hot metal sets up a contrast, which strengthens the case for increasing the illumination so as to reduce this contrast.

Roads represent a comparatively large proportion of the total area of a steelworks, and it would not be economical to extend interior lighting technique to them. If well-designed lanterns are mounted at 25 ft., glare should not be more disturbing than on well-lit public roads.

In reply to Mr. Long's question regarding relative figures of depreciation, I recall a case in which totally enclosed fittings were substituted for open fittings, and the efficiency was increased by about 35%, but I do not think that visored fittings are necessary or desirable in all situations. Fittings must be selected with due attention to the conditions under which they are to function.

I agree with Mr. Hewett that more data on maintenance costs are needed, but these will only be obtained when more planned maintenance is carried out. Although the cost of maintenance has some bearing on the design, it is not satisfactory to increase the initial intensity unduly to compensate for poor maintenance ; it produces a too great variation in the intensity.

In further reply to Mr. Cunnington, I agree that roads running through or parallel to areas floodlit by high-level sources should be illuminated by additional projectors on towers, but it would not be economical to extend this system to roads sited between buildings, or bounded by areas not requiring illumination. The intensity of road lighting must, of course, be related to the intensities in adjacent buildings, so that the time required for the eye to adapt itself from one intensity to another is short.

PROCEEDINGS OF THE AFTERNOON SESSION : 2 P.M. to 4.30 P.M.

Discussion on the Paper—
THE SUPPLY AND DISTRIBUTION OF WATER TO IRON AND STEEL WORKS*

Mr. J. L. Daniel briefly introduced his paper.

Mr. H. R. Pepper (Stewarts and Lloyds, Ltd.) : Some years ago, Stewarts and Lloyds, Ltd., were instrumental in impounding the water of a tributary of the River Welland at a point conveniently near to their Corby Works ; the present works water consumption is about 4,500,000 gal. daily, and approximately half is taken from this Eye Brook Dam.

This last-mentioned supply has three advantages. Firstly, it comes from a source outside the relatively small catchment area in which the Corby Works is situated, and is therefore immune from any possible contamination by works effluent ; secondly, this effluent, after a certain amount of chemical and mechanical treatment, is not of such magnitude as to constitute a prohibitive objection, although its presence is detectable in the relatively small additional supply of raw water from those sources within our catchment area ; and thirdly, the Eye Brook raw water has a relatively low total hardness, and associated low concentration of dissolved solids.

All the raw water pumped to the works is directed to the water-treatment station, and is either distributed from there in the ' as received ' condition, or is treated before distribution to provide softened water. Hard raw waters vary in their response to softening treatment ; in one of our raw water supplies, the predominating hardness is ' permanent,' whereas in another ' temporary ' hardness is in excess. The total hardness of the former is approximately twice that of the latter, and because of its predominating permanent hardness, and also because of a mass effect exerted during precipitation, this water readily responds to chemical treatment. The mainly temporary hard water includes a proportion of total magnesium salts (approx. 4–5 grains/gal.) ; further, because it is drawn from the Eye Brook Dam, which was relatively recently constructed on land which had been under agriculture for a very long time, it is contaminated by decomposing vegetation, and does not respond so readily to our softening treatment. Associated with, and possibly contributing to, the relative difficulty in obtaining from this supply a stable treated water, is a tendency to ' after-precipitation,' following plant filtration through gravity sand filters ; this gave rise to a series of laboratory tests to investigate any possible effect exerted by minute organisms in the raw water on our softening treatment, and/or on the effective filtration after normal sedimentation.

Relatively large-scale laboratory tests were conducted to note the effect of chlorination of the raw water on subsequent softening, sedimentation, and filtration. The Water Treatment Division of I.C.I., Ltd., co-operated with us, and, although no definite conclusions were reached, we formed the opinion that chlorinated samples of the water were much less susceptible to delayed sedimentation, so that the filtered water remained clear.

The water-treatment plant comprises three separate treatment units at the present time, one capable of treating 36,000 gal./hr., and each of the others, 72,000 gal./hr.—a total of 180,000 gal./hr. These provide the 2,500,000 gal. of soft water required daily by the various works departments. They operate on the soda ash–lime (Clark's) principle, with an added coagulant to facilitate sedimentation of the precipitated calcium and magnesium salts.

In providing this treated water, the three softening plants consume the following amounts :

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* *Journal of the Iron and Steel Institute*, 1950, vol. 165, August, pp. 437–453.

Soda ash	1 ton 19 cwt.
'Limbux' lime	1 ton 18 cwt.
S.A. type coagulant	7 cwt.

At the present time our raw-water requirement is met by approximately equal proportions from Eye Brook and Thrapston; these supplies have similar hardness characteristics, as found by the usual tests conducted on samples taken thrice daily. The average total hardness and alkalinity values over the period 1–21st June, 1950, together with the corresponding values for the resulting treated water, are as follows:

	Raw Water		*Treated Water*		
	Total Hardness, °	Methyl Alkalinity	Total Hardness, °	Methyl Alkalinity	Phenol Alkalinity (Total)
Eye Brook	18·9	11·3	1·8	5·2	3·0
Thrapston	17·6	8·6			

Two separate batteries of boilers are in operation; one takes treated water as make-up, and the other operates almost exclusively on condensate. The make-up water for both, however, is conditioned by sodium hexametaphosphate ('Calgon'), the additional cost of which is more than offset by its economy in use and effect. It is by no means unusual for the 350-lb. pressure boilers to function continuously under steam for 12 months or more, since this type of conditioning became standard practice some years ago.

Typical boiler blow-down water analyses are as follows:

	Blast-furnace Boiler-house Water. (Mostly condensate make-up)	Bessemer-furnace Boiler-house Water. ('Becco'-treated water make-up)
Total hardness, grains/gal.	nil	nil
Phenol alkalinity, grains/gal.	9·0	27·0
Total alkalinity, grains/gal.	9·1	35·3
Residual phosphate, grains/gal.	2·8	2·3
Total solids content, grains/gal.	138	220
Specific gravity	1·0015	1·0022

Priming is caused largely by concentration of dissolved solids in the water. Provision of continuous blow-down from the loco boiler is a considerable help, and where feed water for locos has an initially low total solids content, extended periods of trouble-free operation may be anticipated.

Mr. **N. H. Turner** (Appleby-Frodingham Steel Co.): The paper would have been of greater value if data had also been available on the amount of energy consumed in dealing with the water. The water services for a large iron and steelworks recirculating the water may consume an amount of power as large as that absorbed in driving a main rolling mill, and thus any saving is fully worth while.

Is it necessary to treat all the water in the same way? At Appleby-Frodingham, where the raw water is slightly harder, it has been the practice with water that is used for cooling purposes, such as for the blast-furnaces and melting-shops, to treat it only for removal of temporary hardness. Results obtained in the blast-furnaces over a period of ten years indicate that this is good practice, and the saving in treatment costs has been appreciable, amounting over the whole works to a few thousand pounds.

In regard to the water supply to the gas-cleaning plant, Corby are wise to have a separate pipe-line to each washing tower, but I wonder whether a less expensive means of preventing trouble from the induced hardness than bleeding large quantities of water has been investigated.

I should welcome more information on the disposal of sludge by pumping it away; what are the provisions for cleaning the main, and has there been any trouble?

In regard to the inhibited-acid solution, is this pumped through the furnace coolers while they are in operation, or not?

It is not quite clear whether some of the heat taken away from the open-hearth plant is recovered in the feed-water system to the waste-heat boilers.

I fully sympathize with the objection to the use of dirty water for de-scaling, from the maintenance point of view.

I should also like to know whether, in the open reservoirs, there is any algae formation, and if so, whether any trouble has resulted from it.

Mr. **J. L. Daniel**: In regard to the rainfall in North Lincolnshire, I was thinking rather about the West of England, where the rainfall is high. I think that in districts of South Wales and Scotland, 50 in. of rainfall is common.

The disposal of slurry is difficult; the waste pipes have to be cleaned every three or four months, by opening the joints and putting rods through mechanically. Blockage is usually caused by the drying-up of the slurry-pump suction. To overcome it, a connection from the delivery side of the service pumps is made to a float valve, so that when the slurry level in the suction falls, the quick-acting valve automatically lets in water. This prevents any overflow of the suction tank, and it also flushes out the slurry. The slurry pipes are now about to be cleaned again, eight months after the connection was put in, whereas formerly cleaning was necessary every three or four months.

The cleaning of the blast-furnace coolers is done while they are not in operation.

Mr. **Pepper**: Some time ago the blast-furnace management experienced trouble in keeping the inlet mains to the washing towers clear of deposit. The choking was apparently caused by the presence of bicarbonates in the water owing to the circulation and washing of the gas, and it was suggested that the water should be treated with lime, as it passed to the thickener. The cost involved was considerably less than that of taking down the towers at frequent intervals.

Mr. **W. H. North** (Richard Thomas and Baldwins, Ltd.): The fact that a works is sited in a hilly district does not ensure an adequate supply of water. At Ebbw Vale and the old Dowlais works, because of the extremely variable flow in the local streams and rivers, resort had to be made to the construction of reservoirs, at a cost that was considerable, even if not so great as on the flatter ground at Corby.

The North Lincolnshire area has water problems comparable with those of Northants. Although the River Trent is near, its tidal nature causes trouble at the suction end of the pipe-lines, and special arrangements have to be made to settle silt, etc., before treatment. The water has approximately 27° of hardness, with a high proportion of organic matter and of dissolved and suspended solids.

The Tees-side group would appear to be well situated for water; however, cooling water from the Tees has a salt content of about 1700 grains/gal., and where water temperatures are high, deposition of solids, and corrosion, can cause serious problems. Bore holes in the area provide water that is less salt, but that still has large concentrations of dissolved solids—up to 830 grains/gal. The Area Water Board supplies extremely good water, but increasing domestic consumption, coupled with the

relative expense of such a supply of purified water, tends to limit its use to boiler-feed water.

The plan of arranging a central station for the intake and treatment of all incoming water, and for its distribution to sub-stations within the works, is a sound one, but I think that insufficient attention has been given to combining this system with individual systems, each of which would serve one user or group of users. The water would be cleaned, cooled, and re-circulated within each system, and make-up would be drawn from the central supply.

In general, the more points at which the flow can be metered, and consumption checked, the better.

I am in agreement with the author regarding the necessity of making adequate initial installation of pipes, etc., to provide for reasonable development.

Mr. Daniel : Eighty years ago, water was probably used in a blast-furnace only to cool pig, or tools. Although the tendency now is to flood the outsides of furnaces, some are being built in which there is no water-cooling in the stacks at all.

To avoid waste, spring-loaded taps are often installed, as operators tend to open ordinary cocks to their full extent unnecessarily.

Mr. A. Bridge (Appleby-Frodingham Steel Co.) : On p. 446 of his paper, the author states : " Each washing tower is served by a separate pump and 12-in. dia. pipeline ; this facilitates cleaning of the pipes when a tower is out of service." Are these pipes cleaned by acid-treatment or mechanically, *i.e.*, by means of scrapers, etc. ?

On the same page, the author also states : " All water gravitating from washing towers, thickeners, or cooling towers, is contained in open mild-steel launders or concrete channels . . ." I can readily understand this in regard to the washing towers and the Dorr thickeners, but not in regard to the return water from the cooling towers. Would the author say whether there have been any difficulties because of variations in water level at the cooling tower, when the water flows by gravity from the cooling-tower pond in an open launder to the circulating pumps ? Also, what is an ' Abyssinian tube well ' ?

Mr. Daniel : The washing-tower pipes are cleaned by hand when the towers are out of commission. No better method has been discovered.

In regard to the return water in open launders, I cannot say now whether slight drops in water level do occur, but if so, they are negligibly small.

Mr. J. R. Gordon (Stewarts and Lloyds, Ltd.) : In about 1935, when the water demands at Corby were higher than could be met by the existing supply, it was suggested that Abyssinian tube wells might be tried in the region, in a wide stretch of flat ground adjacent to the River Welland. A suitable piece of ground was selected, and 1¼-in. tubes were driven in. These had a solid pyramid point for ease of driving, and some 2 ft. of each tube was perforated with ¼-in. dia. holes. About 5 ft. of clay material was found just under the ground surface, and below the clay was a very dense and compact conglomerate of gravel, varying from about 3-in. lumps to fine sand. It did not seem that there would be much water. The first application of a hand-pump produced only a trickle, but as the suction of the pump was tripped at intervals, and the column allowed to fall down into the bed, the flow from the tube increased as pumping continued, until after perhaps an hour's work the water flowed quite freely.

These wells were tried at various selected points in the area, and the points that seemed to yield the best results were chosen. It was then decided to insert a 3-in. dia. tube similar to the experimental one, and a group of these were inserted and coupled to a petrol-driven pump. A substantial flow of water was obtained, and it was decided to proceed further. Two groups of 18 wells were coupled to a two-column suction pipe, and a maximum flow of water of 1,250,000 gal./day, of excellent purity, as reported by the bacteriologists, was maintained over a period.

The circumstances in which such a supply can be obtained are, however, probably very limited : it so happened that near Corby favourable conditions existed.

Mr. **A. Holt** (Husband and Co., Sheffield, representing the Institution of Water Engineers) : I am responsible, as resident engineer, for an industrial scheme now nearing completion, that will be capable of extracting up to 30,000,000 gal./day of water from the River Don. This water is extremely bad, because of pollution. I would stress the necessity of duplicating the important items of pumping and treatment plant machinery, to ensure, in any contingency, the works supply on which the furnaces and rolling mills depend for their continuity of operation and for safety. This has been done in The United Steel Companies' new scheme at Sheffield, where, apart from the pumping capacity already mentioned, 12,000,000 gal./day of the very bad raw water from the River Don is being treated to potable standard on a continuous-operation basis.

Mr. **M. D. J. Brisby** (B.I.S.R.A.) : Mr. Turner mentioned the high cost of water services. I should like to know why a closer check is not kept on the rise in temperature of furnace cooling water. I believe that in some cases it has been found that, after passing through the cooling system, water emerged at almost the same temperature at which it entered. This would seem to indicate that too much water was being pumped through the cooling system.

A well laid out water system retains a head of water to a much greater extent than a poorly laid out system, and so reduces pumping costs. I should like to know whether attention is paid to this point.

I have sometimes felt that alternative routes in case of breakdown were provided more by chance than by careful planning. Deliberately planned alternative routes could be used not only if a breakdown occurred, but also when routine maintenance necessitated the closing down of certain sections of the water system.

Mr. Daniel : Our costs are based on metered quantities at the works : all the incoming water is metered.

In regard to the temperature rise in open-hearth furnace cooling water, to control the rate of flow, cocks may be set to permit the minimum flow corresponding to a reasonable rise in temperature. It is not uncommon, however, to find that the cocks have later been opened to their full position, and it is advisable to check systematically the positions of all hand-operated cocks.

I think that perhaps our towers are built too high as regards the head of water in the layout. A storage tower to feed an open-hearth furnace might be built to give a pressure of 25 lb./sq. in., whereas a pressure of only 15 lb./sq. in. is required. However, because of the furring-up of pipes, a margin of safety is necessary.

From the diagrams in the paper, it may be seen that alternative routes in case of breakdown exist. As all the lines on the sub-stations are short, the chances of a breakdown occurring are small.

As far as the mains are concerned, the initial cost of providing alternate routes is high. At Corby, there are

separate hard and soft water supplies, the two systems being connected, to provide a temporary alternative in the case of failure of either system.

Mr. **G. C. S. Oliver** (Stewarts and Lloyds, Ltd.): The Eye Brook reservoir presents a problem as regards algae, because it is on some of the most fertile land in England. Mr. Pepper mentioned the chlorination method of destroying algae. My experiments have shown that the chlorine seems to wither up and immobilize them, so that the problem of algae wriggling through the sand of the filters is apparently solved by this method.

Mr. **A. Stock** (Steel Company of Wales, Ltd.): I was very surprised to hear that two 100-ton modern water-cooled open-hearth furnaces are operating at Corby, with a total flow through them of 50,000 gal./hr. Is this an estimated or a metered quantity? I believe the author mentioned that a reduction in the flow is being considered.

At Port Talbot Works, 80-ton water-cooled oil-fired furnaces operate on a flow of 35,000 gal./hr. for each furnace. At Margam, identical furnaces operate on a total flow per furnace of 50,000 gal./hr., and I believe this quantity could be reduced, though certainly not to 35,000 gal./hr. Steps are being taken to increase the quantity at Port Talbot.

I should like to know what is the temperature rise at Corby, and whether trouble is experienced with door jambs through lack of sufficient cooling water.

Mr. **Daniel**: The flow of 50,000 gal./hr. was measured by metering; I cannot give the temperature rise at the moment.

In the initial stages, some trouble from door jambs was experienced; the stoppage of flow was due to silt from the overhead storage tank, and when this was cleared there was no further trouble.

Mr. **R. L. Willott** (John Summers and Sons, Ltd.): The author has remarked on the problem of recovering mill effluent, and a brief description has been given of a new sedimentation filter plant now under construction in Sheffield. We have had such a plant in operation at Shotton for 12 months; it was designed to supply 3,000,000 gal./day, and has been yielding 4,000,000 gal./day of crystal-clear water. Pumping and treatment costs per thousand gallons of filtered and of fresh well water are about equal. Installation costs are a function of well depth, yield per bore hole, and distance: in our case those costs for both types of plant are about equal.

Mr. **Daniel**: Is clean water used for de-scaling, and is it afterwards allowed to run to waste, or is it returned and put through the filtering plant again?

Mr. **Willott**: All our water, 3,000,000 gal./day from the wells, and 4,000,000 gal./day from the filter plant, is pumped into a common delivery main, which feeds all parts of the continuous strip mill; except for about 300,000 gal./day, which is discharged from the tandem cold reduction mill, all user points reject into a common scale pit. The main bulk of scale from this pit is removed by grab at week-ends; 4,000,000 gal./day of raw water is pumped for treatment during the week from this scale pit, and the balance of 3,000,000 gal./day runs to waste. The type of water handled is extremely high in scale, with some oil content.

Mr. **Bridge**: In regard to temperature rises, I think that the 'correct' temperature must be defined, for any set of conditions. If the water circulating is fairly cold, and adequate pumping facilities exist, the additional pumping cost is negligible, because the same number of personnel is required to man the pumps: a little more electricity may be used, but if on the other hand the water returns steaming, evaporation losses are higher, so that more make-up water is necessary, which may be far more costly, from both a purchasing and pumping point of view.

Our process water is obtained from a river, and it is all metered. The meters have to be read every quarter, jointly with the representative of the water undertaking, because we pay for the water. The meters are very reliable, and we have little or no maintenance trouble.

CORRESPONDENCE

Mr. **J. H. Butler** (Stanton Ironworks Co., Ltd.) wrote: On p. 443 of the paper, amounts of water of 500,000 gal./day and 200,000 gal./day are mentioned as required for the gas-cleaning plant, and to cover evaporation losses in the furnace cooling water and the condenser circulating water, whereas on p. 444, a total amount of 800,000 gal./day of make-up water for the furnace and gas plants is mentioned. What is the correct figure? Also, what percentage are these make-up quantities of the total amount of circulating water, what percentage of evaporation and other losses are experienced at your open cooling ponds, and what is the average quantity of blast-furnace gas per hr. obtained from your furnaces?

I assume that cyanides are present in both the gas-cleaning plant sludge and the deconcentration water drawn from the gas-cleaning plant cooling towers; are any complaints received from local authorities regarding the disposal of the latter? I shall be interested to learn how you dispose of the deconcentration water.

On p. 446, perforated screen plates are mentioned as being fitted at the discharge launders to the Dorr thickeners. Are these to prevent any foreign matter, such as broken water-spray nozzles, etc., finding their way to the thickener sludge-discharge pumps?

Do you experience excessive wear on the unchokeable pumps dealing with sludge from the thickeners, and, where it is impossible to run open launders for the gas-cleaning plant water circulation, is it advisable to duplicate any closed pipe-lines in case of choking owing to settlement of the limited amount of entrained sludge?

Mr. **Daniel** wrote in reply: The figures of 200,000 and 500,000 gal./day given on p. 443 are approximate; the figure of over 800,000 gal./day represents the maximum demand. The amount of make-up water is approximately 40% of the total circulating water. Unfortunately there are no means of determining losses in the cooling ponds: these open ponds are connected to the cooling-tower ponds, thus maintaining a constant level in all the ponds.

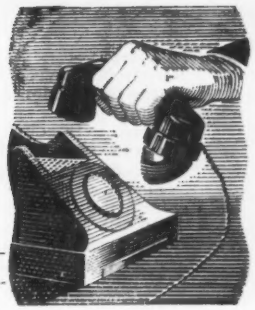
Approximately 11,000,000 cu. ft./hr. of blast-furnace gas is available.

The general question of the toxic content of our works effluents receives attention from our Department of Research and Technical Development and, on a daily routine basis, from our Routine and Research Laboratory. The principal source of cyanides and phenols in the blast-furnace discharge water is the liquor-quenched coke; the concentration, however, of these toxic constituents is considerably lower than the minimum amount permitted by Statute.

The perforated screen plates are placed in the discharge launders for the reasons suggested by Mr. Butler.

Sludge-pump wear is not excessive. Pump impellers have a life of four to five months. All return water from the gas-cleaning plant is carried away in open launders. In plants where this is not possible, I agree that it would be advisable to duplicate any closed pipe-lines.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1951

The Eighty-Second Annual General Meeting of The Iron and Steel Institute will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on **Wednesday to Friday, 30th May–1st June, 1951.**

The following is a detailed programme :

Wednesday, 30th May

Morning Session

10.0 A.M. to 11.0 A.M.
Formal business, including :
Report of Council and Accounts for 1950
Presentation of Prizes and Medals
Induction of Mr. Richard Mather as President

11.0 A.M. to 11.45 A.M.—Presidential Address by Mr. R. Mather

(11.45 A.M. to 12 NOON—Interval)

12 NOON to 1.15 P.M.—Discussion on :

"*The Present Position of the Converter Process : Economic Comparison with other Steelmaking Processes*," by B. Matuschka (*May*, 1951)

1.15 P.M. to 2.30 P.M.—Buffet Luncheon

Afternoon Session

2.30 P.M. to 5.0 P.M.—Presentation of Films by Dr. J. B. Austin (Director of Research, United States Steel Company) : "Study of the Zone in Front of a Blast-Furnace Tuyere by Means of High-Speed Motion Pictures and Models."

Discussion on :

"*The Significance of Equilibrium and Reaction Rate in the Blast-Furnace Process*," by J. B. Austin (*April*, 1951)

Evening

7.0 for 7.30 P.M.—Members' Dinner at the Dorchester Hotel, Park Lane, London, W.1.

Thursday, 31st May

Morning Session

10.0 A.M. to 1.15 P.M.—Joint Discussion on :

"*Aspects of the Blast-Furnace Situation in the U.S.A.*," by Owen R. Rice (Freyn Engineering Company)

"*The Evolution of the All-Carbon Blast-Furnace*," by J. H. Chesters, G. D. Elliot, and J. Mackenzie (*March*, 1951)

"*Radioactive Indicators for Blast-Furnace Refractory Wear*," by E. W. Voice (*Feb.*, 1951)

(11.30 A.M. to 12 NOON—Interval)

1.15 P.M. to 2.30 P.M.—Buffet Luncheon

Afternoon Session

2.30 P.M. to 5.0 P.M.—Joint Discussion on :

"*The Smidth Agglomerating Kiln : Plant and Practice at East Moors Works, Cardiff*," by W. E. Simons (*Jan.*, 1951)

"*Sinter Making at Appleby-Frodingham*," by G. D. Elliot and N. D. Macdonald (*March*, 1951)

"*Investigation of the Effects of Controlled Variables on Sinter Quality. Pt. I—Development of Experimental Sinter Plant and Preliminary Results using Northants Ore*," by E. W. Voice, C. Lang, and P. K. Gledhill (*April*, 1951)

"*The Sintering of Northamptonshire Iron Ore : A Production-Plant Study of Factors Affecting Sinter Quality*," by D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill (*April*. 1951)

Friday, 1st June

Morning Session

10.0 A.M. to 1.0 P.M.—Joint Discussion on :

"*Full-Scale Blast-Furnace Trials*," by J. A. Bond and T. Sanderson (*May*, 1951)

"*Distribution of Materials in the Blast-Furnace. Pt. III—Further Factors Influencing the Distribution of Solids in the Blast-Furnace*," by R. Wild (*Dec.*, 1950)

(There will be an interval between 11.0 A.M. and 11.30 A.M.)

Special Meeting in Austria

The preliminary details given on pp. 201–202 of the February, 1951, issue of the *Journal* remain unchanged except that the party leaving London on **Wednesday, 5th September, 1951,** will go to Gmunden and *not* to Bad Ischl as stated. All travel and hotel arrangements are being made on behalf of the Institute and of the Austrian Reception Committee by Thos. Cook and Son, Ltd., London, in association with Wagons-Lits/Cook, Vienna.

A circular letter containing the prices and further details of the programme and inviting members to apply to join the meeting will be sent out at the end of May ; this letter will also explain what steps should be taken by Members of The Iron and Steel Institute who wish to join the Annual Autumn Meeting of the Institute of Metals, in Italy, of which the outline programme is as follows :

The Institute of Metals—Meeting in Italy

Members of The Iron and Steel Institute and their Ladies who attend the Meeting in Austria will be able to arrive in Venice late on the evening of **Saturday, 15th September.** They will remain in Venice until the afternoon of **Wednesday, 19th September,** when they will be able either to leave by train for London, arriving in the afternoon of Thursday, 20th, September or leave by road for Milan. During the period in Venice there will be a congress of the Associazione Italiana di Metallurgia and, at the invitation of that body, technical sessions of the Institute of Metals. Visits to the following works have been arranged :

(*a*) *Non-Ferrous*
Società Montevecchio (Lead and zinc metallurgy)
Industria Nazionale Alluminio (Extraction of aluminium)
Società Vetrocoke (Coke plant, with adjoining works for manufacture of special constructional glasses and for the production of chemicals and fertilizers)
Venice/Milan Route
Industria Nazionale Alluminio, Bolzano (Electrolytic manufacture of aluminium. Most up-to-date works of its kind in Italy, 150 km. from Venice)
(*b*) *Ferrous*
Ilva. Alti Forni e Acciaierie d'Italia, Stabilimento di Porto Marghera (Venezia) (Steelworks)
Industria Nazionale Alluminio, Stabilimento di Porto Marghera (Venezia) (Ferro-alloys)
Società Industriale "San Marco," Stabilimento di Porto Marghera (Venezia) (Ferro-alloys)

There will also be an official welcome for Members and Ladies by the Mayor of Venice in the Doge's Palace, and various excursions for Ladies.

The programme in Milan will last from the late afternoon of Wednesday, 19th September, until the afternoon of Saturday, 22nd September, when Members and Ladies will be able either to return to London by train arriving in the afternoon of Sunday, 23rd September, or leave by train for Florence; the programme in Milan will contain a joint technical session with the Associazione Italiana di Metallurgia on "*Metals in the Field of Art*," a visit to the 9th Exhibition of Decorative Art, a banquet, a visit to the Instituto Sperimentale Metalli Leggieri at Novara (with lunch at Stresa and the afternoon on a steamer on Lake Maggiore), and visits to the following works:

(*a*) *Non-Ferrous*
Istituto Scientifico Tecnico, Società Italiana Ernesto Breda, Milan
Istituto Sperimentale Metalli Leggeri, Novara (Light metal research)
(*b*) *Ferrous*
Dalmine, Milan (Steel and tube works)
Istituto Scientifico Tecnico, Società Italiana Ernesto Breda, Milan
Società Italiana Ernesto Breda, Milan (Electric production of pig iron)
Ilva. Alti Forni e Acciaierie d'Italia, Lovere
Società F.I.A.T., Mirafiori works, Turin (Automobile manufacture)
Società F.I.A.T., Ferriere Piemontesi, Turin (Steel and rolling mills)

Members and Ladies who go on to Florence will arrive there in the evening of Saturday, 22nd September, and remain until the afternoon of Tuesday, 25th September, when they will leave by train for London, arriving in the afternoon of Wednesday, 26th September. During the period in Florence, ample time will be allowed for visiting museums and other places of artistic interest, and visits will be arranged to the following works:

(*a*) *Non-Ferrous*
Società Metallurgica Italiana, Stabilimenti di Fornaci di Barga (Lucca) (Foundry and rolling mills for copper, brass, aluminium, and light alloys)
Società Metallurgica Italiana, Stabilimenti di Campo Tizzoro (Copper and brass foundry and rolling mills)
(*b*) *Ferrous*
Ilva. Alti Forni e Acciaierie d'Italia, Impianti di Piombino e dell'Isola d'Elba (Blast-furnaces and steelworks)

All travel and hotel arrangements are being made for the Institute of Metals by Thos. Cook and Son, Ltd., London. Detailed prices and fuller particulars of the programme will be sent shortly to all Members of the Institute of Metals. Members of The Iron and Steel Institute who are *not* Members of the Institute of Metals will be advised shortly as to what action they should take to obtain further details of the Meeting in Italy; they are asked *not* to apply direct to the Secretary of the Institute of Metals at this stage.

NEWS OF MEMBERS

▶ Mr. I. A. BAILEY has been appointed a Director of The Mond Nickel Co., Ltd.

▶ Mr. D. L. CAMPBELL has been appointed a Director of the Electric Furnace Co., Ltd., Weybridge.

▶ Mr. J. B. DAVIES has left The United Steel Companies, Ltd., and is now with the Cambridge Instrument Company, Ltd.

▶ Mr. R. GANGULI, formerly Assistant Chemist at the Chittaranjan Locomotive Works, India, has been appointed Scientific Assistant (Metallurgy) with the Bengal Engineering College.

▶ Mr. A. S. GODBEHERE has left the English Steel Corporation, Ltd. to join the Research Department of Messrs. William Jessop and Sons, Ltd.

▶ Mr. M. A. GROSSMAN has left the Carnegie-Illinois Steel Corporation and is now with the United States Steel Company, Pittsburgh.

▶ Mr. R. PARKER, Assistant Lecturer in Metallurgy at University College, Swansea, has been awarded a post-graduate travelling scholarship in extraction metallurgy by the Nuffield Foundation. He will be travelling in U.S.A. and Canada, visiting various plants during the four months commencing June, 1951.

▶ Mr. P. B. PARKS has relinquished his position of Metallurgist and Steel Foundry Manager, the Hong Kong and Whampoa Dock Co., Ltd., Hong Kong.

▶ Dr. L. B. PFEIL, Director of The Mond Nickel Co., Ltd., and Head of the Company's Research and Development Department, has been elected a Fellow of the Royal Society.

▶ Mr. N. D. SHEPHERD has left the Research and Development Department of The United Steel Companies, Ltd., to take up an appointment with Messrs. D. Napier and Son, Ltd., Liverpool.

▶ Mr. A. P. T. TAYLOR-GILL has left Kuala Lumpur, Malaya, and is now in Melbourne, Australia.

▶ Mr. G. A. WHITTAKER has been awarded the B.Sc. (Hons. Met.) degree of the University of Manchester and the associateship of the Institution of Metallurgists. He is now with Head Wrightson Stampings, Ltd.

▶ Mr. C. T. WILSHAW has been appointed Chief Metallurgist with Messrs. F. Perkins, Ltd., Peterborough.

▶ Mr. D. R. WOOD, of the Development and Research Department of The Mond Nickel Co., has been appointed Leader of the Melting and Casting Section.

Obituary

Mr. H. LUND, of the Department of Research and Technical Development, Messrs. Stewarts and Lloyds, Ltd., on 22nd February, 1951.

Mr. L. W. T. WEBB, Casting Superintendent, I.C.I. Metals, Ltd., on 25th February, 1951.

Mr. G. GLENN, Honorary Member and Past-President of the Sheffield Metallurgical Association, on 1st March, 1951.

CONTRIBUTORS TO THE JOURNAL

B. Matuschka—After serving in the Austrian Navy during the First World War, Dr. Matuschka spent one year at the Technische Hochschule, Vienna, followed by two years at the Montanistische Hochschule at Leoben where he obtained a distinction. In 1921 he was appointed steelworks assistant with the Bleckmann Stahlwerke at Mürzzuschlag and became steelworks manager in 1924. With the amalgamation of the firms, Schoeller and Bleckmann, in 1926, he was appointed manager of the combined open-hearth and electric steelworks at Ternitz.

B. Matuschka

J. B. Austin

Four years later Dr. Matuschka became manager of the forge at Ternitz and later he also took over the management of the steel and grey-iron foundry. He was responsible for the erection of the first high-frequency steel melting furnace in Austria and in 1934, in conjunction with the A.E.G., Vienna, he erected the (then) largest high-frequency furnace in Europe. Dr. Matuschka was awarded the doctorate of mining science in 1930. He was a member of the Steelworks Committee of the Verein deutscher Eisenhüttenleute, Düsseldorf, and Chairman of the Steelworks Committee of the Eisenhütte Österreich at Leoben. In 1941, he took over the direction of the Hüttenwerke, Donawitz, of the Österreichisch-Alpine Montangesellschaft. Up to the end of 1950, he was Director of the Iron and Steel Division of the Alpine Montangesellschaft in Leoben. In the summer of 1951 he is to become a technical consultant to the iron and steel branch of the newly formed Vereinigte Österreichische Eisen- und Stahlwerke, Linz.

F. Ellis, B.Sc.(Eng.)—On the staff of the City and Guilds College, London. Mr. Ellis served an apprenticeship in the locomotive workshops of the (then) G.W. Railway. He graduated from the City and Guilds College with First Class Honours in 1949 and was awarded the Bramwell Medal. In the same year he obtained a Clayton Fellowship of the Institution of Mechanical Engineers. Mr. Ellis is at present carrying out research into problems of hot and cold rolling.

J. B. Austin, Ph.D.—Director of Research, United States Steel Company, Kearny, New Jersey. Dr. Austin was awarded the degree of Chemical Engineer of Lehigh University, Bethlehem, Pennsylvania, in 1925, and obtained a Ph.D. degree in physical chemistry from Yale University in 1928. In the same year he joined the staff of the Research Laboratory of the United States Steel Corporation and became Assistant Director of the Laboratory in 1944. Two years later he was appointed Director of Research for the United States Steel Corporation of Delaware, and when this Company merged into the United States Steel Company, he was appointed to his present position. Dr. Austin's work has been largely concerned with the properties of metals and refractories at high temperature, and with the application of thermodynamics to processes for making or treating steel.

He is a Trustee for the American Society for Metals and was invited to give the Society's Campbell Memorial Lecture in 1946. He is Vice-President of the Iron and Steel Division, and a member of the Executive Committee of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers. Dr. Austin is associated with the Committee on Chemical Warfare of the Research and Development Board of the Department of Defence of the United States Government.

(*Dr. Austin is the author of a paper published in the April issue of the* Journal.)

IRON AND STEEL ENGINEERS GROUP

The **Fifteenth Meeting** of the Group will be held at 4 Grosvenor Gardens, London, S.W.1 on **Tuesday, 19th June, 1951.**

Ablett Prize, 1950

On the recommendation of the Engineering Committee it has been decided that the Ablett Prize for 1950, value £100, should be divided between Mr. D. A. Wise and Dr. L. N. Bramley (both of the British Iron and Steel Research Association) for their paper "A Proposed Method of Specifying Travel-Motion Performance for Steelworks Overhead Cranes," published in the April 1950 issue of the *Journal* (vol. 164, p. 439).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

North-East Coast Laboratory

The new Laboratory of the Iron Making Division, at Normanby, near Middlesbrough, was informally opened on 22nd February by a luncheon and cocktail party attended by Mr. R. Mather, Chairman of Council, Mr. B. Chetwynd Talbot, and the members of the Iron Making Panel. The new B.I.S.R.A. experimental establishment at the Redcar works of Messrs. Dorman, Long and Co., Ltd., which houses the plant for the investigation of ore pelletizing and sintering, was also visited. In a short speech Mr. Mather welcomed the arrival of B.I.S.R.A. in the greatest iron-producing area in the country, and replies were made by Mr. W. C. Bell, Sir Charles Goodeve, and Dr. H. L. Saunders.

NEWS OF SCIENCE AND INDUSTRY

Sheffield Metallurgical Association

The list of officers for 1951 is as follows :

President
E. T. GILL, B.Sc., F.I.M.

Vice-Presidents
E. W. COLBECK, H. HICKS, F. H. SANITER, T. H. ARNOLD

Hon. Treasurer	**Hon. Secretary**
T. H. ARNOLD	J. BURNETT
Hon. Librarian	**Hon. Proc. Secretary**
T. G. CHADWICK	H. W. PINDER

Members of Council

H. ALLSOP	J. RAIT, D.Sc.
B. BAGSHAWE	G. ROBINSON
R. C. BAKER	J. H. SPALTON
S. HARRISON	G. E. SPEIGHT
P. JUBB	B. E. G. R. WILKINSON

Mond Nickel Fellowships

The programme for the Mond Nickel Fellowship awarded to Mr. F. R. H. ALLON (*see* February, 1951, issue of the *Journal*) is as follows : To study the methods of moulding, steelmaking, casting, heat-treatment, and testing of carbon and alloy steel castings in the U.S.A. and Canada.

E.T.S. Gold Medal

The Council of the Electrodepositors' Technical Society has awarded the E.T.S. Gold Medal for 1951 to Dr. S. Wernick, Honorary Secretary of the Society.

New Corrosion Group

An inaugural meeting of the Corrosion Group, which is being formed by the Society of Chemical Industry,

is to be held on 17th May, 1951, at the Royal Institution, 21 Albemarle Street, London, W.1, at 6.30 p.m. An Address will be given by Dr. U. R. Evans, F.R.S., and all those interested in this field of work are invited.

Welding Summer School

The British Welding Research Association is to hold a Summer School on "Welding Design and Engineering" at Ashorne Hill, near Leamington Spa, Warwickshire, from Friday, 25th May to Saturday, 2nd June, 1951. The course will consist of two introductory days during which recent developments in welding practice and metallurgical aspects of welding ferrous and non-ferrous metals will be discussed. These will be followed by 5½ days devoted to general lectures.

Application forms and further particulars should be obtained from the Secretary, British Welding Research Association, 29 Park Crescent, London, W.1, as soon as possible.

Institute of British Foundrymen

The 48th Annual Conference of the Institute of British Foundrymen, organized by Newcastle-upon-Tyne Branch, will be held at Newcastle-upon-Tyne from 12th to 15th June, 1951. Mr. Colin Gresty, President-Designate and a member of the Newcastle Branch, will be inducted into the Chair.

Chemical Conference, 1951

The Diamond Jubilee Meeting of the American Chemical Society, the XVIth Conference of the International Union of Pure and Applied Chemistry, and the XIIth International Congress of Pure and Applied Chemistry will be held during September, 1951.

To commemorate the 75th Anniversary of the founding of the American Chemical Society, a meeting will be held from 3rd to 7th September. The International Union will convene from 8th to 9th September, and the four-day International Congress is arranged for 10th–13th September. Delegates will be able to participate in the fiftieth anniversary celebrations of the establishment of the U.S. National Bureau of Standards on Friday and Saturday, 14th and 15th September.

Lecture Courses in Process Instrumentation

Courses in this subject have recently been initiated by the Department of Coal, Gas, and Fuel Industries with Metallurgy at the University of Leeds. The course, which will ultimately be taken by all degree and post-graduate diploma students in the subjects of gas and chemical engineering, ceramics, and process metallurgy, is to be given in two parts. The first part, which commenced in the current session, is "The Measurement of Process Variables," and deals with principles and methods of measuring such quantities as pressure, temperature, fluid flow, etc. The second part, "Automatic Control," will commence in the following session and will deal with the theory and practice of automatic controls as applied to the process industries.

These lecture courses, in common with other lecture courses in the University, are open to external students by arrangement with the Department of Extra-Mural Studies.

School of Gas-Turbine Technology

The School of Gas-Turbine Technology, which is the responsibility of Power Jets (Research and Development) Ltd., offers facilities which are unique in the world, both in relation to aero-engine and industrial gas-turbine technology. The School uses many sectional and running engines and has excellent residential facilities. These facilities, including the engines, which are available for demonstration running, can be put at the disposal of special 'courses' of any required duration, by arrangement.

Electrical Engineering at Cambridge

The President and Council of the Institution of Electrical Engineers provided the endowment of a Professorship of Electrical Engineering at the University of Cambridge for a period of five years from the Michaelmas Term, 1945. A gift of £71,000, subscribed by member firms of the British Electrical and Allied Manufacturers' Association, has now been made to the University for the permanent endowment of the Chair of Electrical Engineering.

Alloy Steels Association

Mr. W. E. A. REDFEARN, a Special Director of the English Steel Corporation, Ltd., has been elected Chairman of the Alloy Steels Association in succession to the late Major Guy Newton. Mr. Redfearn is also President of the National Association of Drop Forgers and Stampers.

Brown, Bayley's Steel Works, Ltd.

The entire steel business of Brown, Bayley's Steel Works, Ltd., has been taken over by the Subsidiary Company, Brown, Bayley Steels, Ltd.

Research in Germany

Results of research, sponsored by the D.S.I.R., in Germany after the war are given in Reports issued under the title "Sponsored Research (Germany)." The Reports, which are available to Industrial Research Departments, Universities, and individual research workers from the D.S.I.R., 5–11, Regent Street, London, S.W.1, are of importance mainly to designers and users of gear wheels, although some of the Reports will be of interest to the metallurgist.

Industrial Publication

A handbook of technical data and information on the composition and use in heat control of Kimolo (Moler) Insulating Bricks has been issued by Cellactite and British Uralite, Ltd.

The booklet contains colour diagrams contrasting surface temperatures and heat losses from walls insulated with the material, with uninsulated walls. Calculations on savings in fuel costs, using Kimolo bricks for furnace-wall insulation, are given.

Changes of Address

LAPOINTE MACHINE TOOL CO., LTD., has removed its offices to the new factory on the Watford By-Pass. All communications should now be addressed to: The Lapointe Machine Tool Co., Ltd., Otterspool, Watford By-Pass, Watford, Herts. (Tel.: Gadebrook 3711-2).

ELECTRIC FURNACE CO., LTD. The Heat-Treatment Division of the Company has been transferred from Leeds to Wellington Street Extension, Burton-on-Trent.

DIARY

17th May—INSTITUTION OF MINING AND METALLURGY—Annual General Meeting—Geological Society, Burlington House, London, W.1, 4.0 P.M.

17th May—SOCIETY OF CHEMICAL INDUSTRY—Inaugural Meeting of new Corrosion Group. Address by Dr. U. R. Evans—Royal Institution, 21 Albemarle Street, London, W.1, 6.30 P.M.

25th May–2nd June—BRITISH WELDING RESEARCH ASSOCIATION—Summer School in Welding Design and Engineering—Ashorne Hill, Near Leamington Spa, Warwickshire.

28th May–6th June—THIRD WORLD PETROLEUM CONGRESS—The Hague, Holland.

30th May–1st June—IRON AND STEEL INSTITUTE—Annual General Meeting—4 Grosvenor Gardens, London, S.W.1, 10.0 A.M.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Possible Annual Production of Steep Rock Iron Ore Seen as 10 Million Tons. D. Reebel. (Steel, 1950, vol. 127, Aug. 21, pp. 88–93, 110). It is believed that there are at least 10^9 tons of high-grade hematite ore in the Steep Rock Lake area. This is of importance due to the declining Mesabi reserves and it requires only a 140-mile rail haul to existing Great Lakes shipping facilities at Port Arthur, Ontario. Recovery of this ore is involving large engineering works including the diversion of the river Seine and the drainage of a portion of the Steep Rock Lake.—A. M. F.

How Much Iron Ore in Brazil? J. van N. Dorr. (Iron Age, 1950, vol. 166, Aug. 17, pp. 81–84; Aug. 24, pp. 79–82). This paper emphasizes the great potentialities of the Central Minas Gerais area as a future source of iron ore.—A. M. F.

Conservation of Resources. H. Sutton. (United Nations Scientific Conference: Metal Industry, 1950, vol. 77, July 14, pp. 19–22; July 21, pp. 35–38; July 28, pp. 57–58). This is a summary of many papers, presented by experts of many countries at the United Nations Scientific Conference. The author briefly surveys nine papers dealing with techniques, possibilities, costs, and other features of mineral discovery in several countries. Four papers dealing with the outlook for further discovery are next summarized, three of these referring specifically to Australia, North and South America, and Great Britain. Three papers on the conservation of metals in use, one of which deals specifically with lead, completed this part of the Conference. The following part was devoted to six papers on the conservation by corrosion control. These deal with the staggering cost of corrosion and the methods being used to prevent it. Finally, the possibilities of conservation by substitution are outlined in five papers dealing with the future uses of light metals, especially titanium and magnesium. One paper describes the extraction of the latter metal from sea water.—P. M. C.

World Iron Ore Resources and Their Utilization. (United Nations Department of Economic Affairs, 1950). This Report was prepared by the Economic Development Section of the Division of Economic Stability and Development in the United Nations Department of Economic Affairs. It presents an appraisal of the economic feasibility of developing iron and steel production in the underdeveloped areas of the world. The resources of iron ore and coking coal in these areas and the possibilities and economic aspects of exploiting them are examined. There are 31 tables, six charts, and three maps.

ORES—MINING AND TREATMENT

The Development of the Sludge Settling Process and Its Importance for the Working-Up of Iron Ores. E. Bierbrauer. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 273–282). The theoretical basis and industrial development of the sludge settling process, which depends on the use of the ore-sludge itself instead of water as a settling medium, are described. The special importance of the new process lies in the field of beneficiation of iron ores, since with its aid it is possible in a simple way and with high efficiency to effect a sharp separation of coarse-grained ores (up to 150 mm. particle size) into concentrate, middlings, and rock. It is therefore applicable to that range of ore sizes which up till now has been difficult to treat, and it may also serve as a preliminary separation so that the more costly fine particle process may be carried out on an already enriched ore.—J. P.

Beneficiation Methods for Southern Iron Ore. E. H. Rose. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 221–242). The author discusses the possible methods of beneficiating the high-silicon iron ore found in the Birmingham (Alabama) district, consideration being given to gravity concentration, flotation, and magnetic concentration. Owing to the fundamental constitution of the ore, reduction roasting followed by magnetic concentration is the most applicable process, but entails a higher operating cost.—G. F.

The Beneficiation of Northern Iron Ores. F. X. Tartaron. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 115–128). The beneficiation of low-grade iron ores of the northern districts of the U.S.A., necessitated by the depletion of the high-grade ore reserves, is discussed. Gravity, magnetic, and flotation processes for concentrating the ore and methods of agglomerating the concentrate are briefly described, the importance of the new pelletizing process being emphasized.—G. F.

High Grade Iron Ore from Low Grade Deposits. R. W. Hedges. (Iron Age, 1950, vol. 166, Aug. 3, pp. 79–84). A new method of ore beneficiation called heavy-media separation separates iron-bearing components of iron ore from silica by making use of their different specific gravities in a medium consisting of a suspension of finely ground ferrosilicon in water. The specific gravity of this medium can be mantained within $\pm 0{\cdot}01$ of a predetermined figure and, owing to its magnetic properties, it can be readily recovered. Descriptions of various plants using this method are given.—A. M. F.

FUEL—PREPARATION, PROPERTIES, AND USES

Advances in Combustion Control in Pacific Coast Plants. R. S. Coulter. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 307–317). The author discusses the advent and subsequent improvement of instrumentation of open-hearth and reheating furnaces in American Pacific Coast works, and the changeover from manual to automatic control of combustion. Some of the most important devices and their functions and maintenance are briefly described, and it is emphasized that such devices are simply tools which must be used intelligently to ensure maximum benefit.—G. F.

A New Development in Combustion Diagrams. J. D. Keller. (Blast Furnace and Steel Plant, 1950, vol. 38, Feb., pp. 193–195). The author gives details of a universal combustion diagram invented by Raymond Pigrais. This obviates the necessity for preparing separate charts for each fuel dealt with, as is necessary when using the existing Ostwald charts. The characteristic which Pigrais utilized was that the oxygen content in any flue-gas analysis can, with suitable reservations, serve as a universal criterion of the proportion of excess air which is present.—J. P. S.

Developments in the Steel Plant Combustion Field. H. V. Flagg. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 67–70). The author discusses the importance of fuel economy as a result of increasing difficulties found in the supply, quality, and cost of fuel. Owing to extended facilities for rapid charging, one new open-hearth furnace is now making 450-ton heats in about 12 hr. with fuel consumption below 2·5 million B.Th.U./ton. Other improvements in the industry leading to greater fuel economy are discussed including the 'high speed' heating of uniform sections such as rounds for seamless tubes. The latter cuts the heating time considerably and reduces fuel consumption to less than half its previous value.—J. P. S.

Boilers for Steel Mills. F. X. Gilg. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 108–112, 136). Some modern boilers, recently installed by the Babcock and Wilcox Company, are illustrated and described. The author points out that from these illustrations and descriptions it is apparent that boilers for steel mills must be capable of burning several of the by-product fuels available in steelworks. Other requirements, which are met by the boilers described, are efficient steam separating devices and oversize steam drums. Also taken into account is the necessity to eliminate maintenance and standing time required to replace boiler and superheater tubes which have been eroded by dust-laden gases.—J. P. S.

Recovery of Waste Heat in a Heat-Treatment Furnace. G. Lipietz. (Fonderie, 1950, June, pp. 2075–2080). An account is given of a French plant, in which the waste heat from an annealing furnace is made to produce electric power and, simultaneously, to heat a number of places in a works. The collection of the waste gas, the boilers, the system of steam separation, and the exchangers are described.—R. S.

Washing and Blending of Coal. R. P. Bremner and C. A. Covington. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 183–201). Descriptions are given of the coal cleaning and blending plants of the Dehue and Nemacolin Mines of the Youngstown Sheet and Tube Co., and of the process of coal mixing in the Youngstown district.

G. F.

Dense-Media Coal Washers: General Plant Design. F. F. Ridley. (International Coal-Preparation Conference: Iron and Coal Trades Review, 1950, vol. 161, Aug. 18, pp. 345–348). *See* Journ. I. and S.I., 1951, vol. 167, Feb., p. 208.

Carbonizing Properties: West Virginia Coals from the Eagle, No. 2 Gas, Pocahontas No. 3, and Pocahontas No. 4 Beds. J. D. Davis, D. A. Reynolds, R. E. Brewer, W. H. Ode, B. W. Naugle, D. E. Wolfson, and G. W. Birge. (United States Bureau of Mines, 1950, Bulletin 493).

Radioactive Isotopes as Tracers in Steel Industry Research. J. P. Graham. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 264–277). The author discusses the possible metallurgical applications of radioactive tracers and describes some of the problems to which they have already been applied, dealing in particular with the use of radioactive sulphur in a study of the distribution of sulphur during the coking of coal.—G. F.

Importance of Chemicals from By-Product Coking of Coal. R. O. Bowman. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 328–339). The development of the by-product coking industry is discussed and its importance emphasized. The applications of some of the most important by-products, including benzol, coal tar and its derivatives, and ammonium sulphate, are indicated.—G. F.

The Mechanism of the Cyclone. G. Tarján. (Bányászati és Kohászati Lapok, 1950, vol. 5, Nov., pp. 610–614). [In Hungarian]. The author presents a mathematical analysis of the laws governing the theory of cyclones for cleaning gases.—E. G.

Cokemakers Face Gas Purification Program. H. A. Collmar. (Steel, 1950, vol. 127, July 17, pp. 102–104). The increase of sulphur in coking coals soon may require the installation of equipment for the removal of hydrogen sulphide to render the coke-oven gas suitable for use in reheating furnaces. The author describes the Koppers vacuum activation sulphur recovery process of gas purification. In this process the coke-oven gas is scrubbed with a solution of sodium carbonate which absorbs the hydrogen sulphide and hydrogen cyanide from the gas; these two constituents are then separated out as by-products.—A. M. F.

Natural Gas Gives Flexible Combustion Control. W. A. Sterner. (Iron and Steel Engineer, 1950, vol. 27, Aug., p. 122). A brief description is given of the two uses of natural gas at the Washington Steel Corp., where this gas has been selected as the fuel for heat-treatment as well as to fire the 50-h.p. vertical tube boiler which supplies steam to heat the pickling tanks.—M. D. J. B.

Preliminary Classification of Coals for Gas Producers. L. Szklarska-Olszewska. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 1, pp. 15–29). [In Polish]. Samples of coals from nine different mines in Poland were tested to determined their suitability for gas producers. The basis on which these coals were classified is explained.—W. J. W.

Modern Views on Gas Producers. G. W. C. Allan. (Iron and Coal Trades Review, 1950, vol. 160, June 2, pp. 1213–1219). The author reviews the difficulties encountered in gas-producer operation and discusses the reasons for the considerable variation in gas quality. It is shown that one of the most important factors in obtaining good quality gas is the maintenance of an even fuel bed, and in this respect coal-feeding devices and ashing methods are considered. Operating conditions and instrumentation are briefly discussed, and attention is given to the properties required in a good producer coal and to the cost considerations in producer plants. The importance of competent producer design is emphasized.—G. F.

Eliminating Water from Producer Gas without Substantial Reduction of Its Tar Content. J. Puch. (Bányászati és Kohászati Lapok, 1950, vol. 5, Sept., p. 530). [In Hungarian]. A method of removing water from producer gas is described in which the gas remains in the cooler only for about 10 sec. A considerable part of the water precipitates but the tar remains in the gas. Experiments have been carried out on a laboratory scale with a cooler dealing with 100 cu. m./day requiring about 14 litres/hr. of cooling water. About 80% of the water in the gas was removed by this apparatus.

R. A. R.

Application of Superimposed Precipitators. R. E. Touzalin. (Journal of Metals, 1950, vol. 188, Apr., pp. 656–660). A brief description is given of several blast-furnace-gas cleaning installations consisting of tower scrubbers with superimposed electrostatic precipitators. Detailed illustrations are presented and it is emphasized that this type of installation is especially valuable in plants with limited available space.

G. F.

Modern Blast Furnace Gas Cleaning Practices. G. P. Burks. (Journal of Metals, 1950, vol. 188, May, pp. 746–750). The programme of modernization of the blast-furnace-gas cleaning installations at the Gary works of Carnegie-Illinois Steel Corp. is described. The primary tower washers recently built show the trend at Gary works towards the simplified static tower washer for primary gas cleaning. Two plate-type electrical precipitators have been installed to replace one of the Theissen washer houses, and four tube-type electrical precipitators are being added, two to clean primary gas and two to clean the gas still more for under-firing coke ovens.

It is expected that eventually all the Theissen washer houses will be replaced. Three high-efficiency boilers have also been installed to burn fine-cleaned gas.—G. F.

Gas Purification by Centrifugal Systems (Cyclones). Miguel A. Artes Prat. (Industria y Química, 1950, vol. 12, Mar., pp. 8–12, 25). [In Spanish]. The author attempts to condense modern ideas, tendencies, and conceptions regarding gas purification equipment. First, the conditions of operation must be determined; second, the required degree of efficiency must be established. The choice of equipment can then be made, based on maximum uniformity and lowest cost. The mathematical determination of the efficiency of cyclones is explained and some present-day tendencies in the manufacture of cyclone equipment are considered. Problems peculiar to the manufacture of the 'multicyclone' type of equipment are mentioned, and reference is made to the theoretical conceptions of C. B. Shepherd and C. E. Lapple (Industrial and Engineering Chemistry, 1940, vol. 32, p. 1246) and others.

R. S.

The Efficiency of Dust Removal Plant. K. Guthmann. (Stahl und Eisen, 1950, vol. 70, May 11, pp. 420–422). The various ways in which the efficiency of dust removal from gases has been measured are reviewed. It is shown that they suffer from the defect that they do not correspond to the conditions under which the plant has to operate or are so dependent on the nature and size distribution of particles in the gas that figures quoted by makers may be quite misleading when applied to a particular industrial problem. The concept of an efficiency which takes into account working costs is suggested as being of more value.—J. P.

Utilization of Low-Calorific-Value Blast-Furnace Gas. (Bányászati és Kohászati Lapok, 1950, vol 5, Oct., p. 570). [In Hungarian]. Experiments on utilization of blast-furnace gas for heating open-hearth furnaces have been carried out. The calorific value of the gas was increased by mixing it with a propane–butane mixture. The enriched gas required cleaning. In addition to saving fuel, this enriched blast-furnace gas improved the quality of the steel produced because of the low sulphur content of the gas.—E. G.

Use of Heavy Fuel Oil in the Foundry. G. Ulmer. (Fonderie, 1950, Aug., pp. 2153–2160). The author states the advantages and disadvantages of using heavy fuel oil in the foundry. The uses are classified and some details of current plant using this type of fuel are given. Emphasis is laid on the ease of handling and stocking. Fuel-oil firing for heat-treatment and melting furnaces is discussed. The characteristics of fuel oil are summarized from the points of view of thermal efficiency, the obtaining of high temperatures, flexibility of control, and lesser danger of harmful effects from sulphur. The use of fuel oil in the following types of plant is discussed: Crucible, rotary and reverberatory furnaces, malleable cast-iron annealing furnaces, steel hardening furnaces, enamelling furnaces, and foundry baking stoves.—R. S.

TEMPERATURE MEASUREMENT AND CONTROL

Measurement of Open Hearth Bath Temperatures. H. T. Clark. (Instrument Society of America: Industrial Heating, 1950, vol. 17, Mar., pp. 458–464). Two general techniques of measurement of open-hearth bath temperature are considered. After discussing the advantages and disadvantages of thermocouple methods, the author deals with radiation methods. An immersion pyrometer is described in which the slag and metal are blown away from the end of a steel tube exposing an area of molten steel to observation. Measurement is made by photoelectric or thermopile techniques. A reading may be taken with an immersion of 5–10 sec. The short immersion time means that the instrument is not damaged by overheating, thus reducing operating and maintenance costs.—J. A. L.

Continuous Temperature Measurement of Liquid Steel in the Furnace. D. Hardwick and H. Everard. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 147–148). Continuous records of the temperature of steel in a side-blown converter have been obtained throughout the blowing operation by fitting a Pt/Pt–Rh thermocouple with a specially designed protective sheath into the refractory wall during the lining of the vessel. Results from a number of trials have indicated that this arrangement could be of general application for steel-melting research and possibly for the works control of steelmaking.

The Use of Platinum Thermocouples *in Vacuo* at High Temperatures. A. G. Metcalfe. (British Journal of Applied Physics, 1950, vol. 1, Oct., pp. 256–258). In the course of thermal analysis on cobalt-base alloys *in vacuo* with platinum/platinum–13% rhodium thermocouples it has been found that the e.m.f. developed at any temperature gradually falls. The principal cause of this is believed to be the transfer of rhodium to the platinum wire *via* the vapour phase. This effect can be reduced considerably by using platinium with 1% of rhodium in place of the platinum wire.—R. A. R.

Automatic Control of Electric Furnaces for Heat Treatment. L. Walter. (Metallurgia, 1950, vol. 41, Apr., pp. 326–351). A review is made of modern trends in the automatic control of furnace temperature in heat-treatment furnaces. The need for the choice of a controller with suitable characteristics for any given job and the matching of response and control times to avoid such undesirable phenomena as 'hunting' are stressed. The relative merits of 'on-off,' 'high-low,' 'multi-step,' and gradual control are discussed. The types of mechanism used are described, including chopper bar, potentiometric, and electronic controls. Time–temperature control cycles are also mentioned.—J. J.

The Use of a Polarizer in the Disappearing Filament Optical Pyrometer. R. G. Grovanelli and W. R. G. Kemp. (Journal of Scientific Instruments, 1950, vol. 27, Mar., pp. 69–71). The use of a polarizer, orientated at a suitable angle in the viewing system of an optical pyrometer is found to give complete disappearance of straight flat pyrometer filaments for apertures considerably larger than are permissible in conventional pyrometers. Larger apertures result in higher visual resolution, and greater precision is thereby obtained.—H. D. W.

Applications of the Electronic Tubes to the Measurements of Temperature. J. Schwartz. (Microtecnic, 1950, vol. 4, May–June, pp. 159–164; July–Aug., pp. 209–216). A survey of the various purposes for which temperature measurements are being used is given together with the available means of performing such measurements as well as for regulating or controlling sources of heat according to measured temperatures. For the application of these features, the means of dilation, thermo-sensitive elements, thermocouples, resistance thermometers, optical pyrometers, and photo-electric cells may be employed. A description of indicating equipment has been included, comprising instruments which directly use a variation of length or of pressure to provide a visual indication of temperature, electric A.C. and D.C. low-voltage and current meters, electrical null-method bridges, and recording instruments.—H. D. W.

Bath Temperature Measurements. J. G. Mravec. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 172–182). Data from 16 steelmaking firms are presented, comparing the use of the immersion thermocouple and the immersion blowing-tube pyrometer in American practice. The former is superior in accuracy, reliability, and ease of handling, whilst the latter, so far confined to open-hearth steel baths, has lower maintenance costs. The value of immersion pyrometry is discussed.—G. F.

Measuring and Control Apparatus in Heating Engineering. R. Hase. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, July, pp. 577–578). The author reviews recent developments in pyrometry and temperature control. He draws attention to a new platinum resistance thermometer for temperatures up to 750° C., marketed by Degussa, Hanau, and notes that Germany is much behind the U.S.A. in the use of photocells in optical pyrometry. Among regulators, an electro-pneumatic system devised by Hartmann and Braun, Frankfurt a. M., is worthy of note. In this the path to a photocell is interrupted by the pointer of a millivoltmeter actuated by the thermocouple. The photocell actuates a small lever which opens or closes a nozzle in a pneumatic circuit. The pressure impulses are of sufficient strength to control the action of a large membrane valve in a furnace installation.—J. G. W.

Infra-Red Photography. A Contribution to Industrial Pyrometry. G. Naeser and W. Pepperhoff. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 293–295). The intensity of infra-red radiation from various parts of a radiating body is recorded photographically by the following technique. The source is focused by a rock-salt lens on a thin layer of a substance such as silver mercuric iodide or cuprous mercuric iodide, which undergoes an allotropic colour change at a moderate temperature. The indicator film is

deposited on a glass plate and made sensitive to all wavelengths by coating with a layer of lamp black. Those parts of the image corresponding to the low intensity of the source have the colour of the low-temperature allotrope, those corresponding to the high intensity have the alternative colour, and those corresponding to medium intensities have an intermediate colour. The infra-red pictures are photographed with an ordinary camera using suitably sensitive plates. The use of such equipment is illustrated by an example of a picture of an annealing furnace, the two halves of which have been coated with different refractory washes. The infra-red, but not the visible, radiation from the two halves can be clearly seen to be of different intensities.—J. P.

REFRACTORY MATERIALS

The Choice of Particle Size in the Preparation of Dolomite for Refractories. G. Trömel. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 153–157). The investigations into the effect of particle size on packing density, principally those described in the Special Reports Nos. 33 and 35 of The Iron and Steel Institute, are reviewed. Whereas with spherical particles, only certain sizes may be present if maximum packing density is to be attained, burnt dolomite requires a continuous range of sizes. This type of particle mixture can be obtained with conventional grinding equipment by suitable choice of grinding conditions.—S. P.

The Refractory Properties of Alunite. III—Effects of Clay Additions on the Stabilization of Alunite. J. O. Knížek and H. Fetter. (Transactions of the British Ceramic Society, 1950, vol. 49, June, pp. 251–257). An attempt to improve the firing properties of alunite by admixtures of 6 to 33·3% of clay is reported. It was concluded from the experiments that the introduction of such clay is not practicable, since the alunite samples showed a pronounced tendency to bloat and an excessive amount of glass formation when fired at 1600° C. When the clay addition was reduced 6%, a coarsely crystalline open structure lacking in glass was obtained after firing at 1600° C. No mullite was found in any of the test samples, probably because of the alkalis. Alpha and β-Al_2O_3 were thought to be present, but the proportions could not be established.—E. J. D. S.

The Refractory Properties of Alunite. IV—Firing Properties and Mineralogical Transformations of Alunite-Alumina. J. O. Knížek and H. Fetter. (Transactions of the British Ceramic Society, 1950, vol. 49, June, pp. 258–268). Three alunite ores of different compositions were calcined at temperatures ranging from 700° to 1050° C. and freed from soluble sulphates. The aluminous residues were dry-pressed and fired at 1400° to 1600° C. Shrinkage, apparent porosity, bulk density, specific gravity and linear change on reheating to 1600° C. were determined. Transverse strength was almost impossible to determine, owing to cracks, except on a calcined alunite containing about 44% SiO_2. Volatilization of alkalis remaining through incomplete removal of soluble salts was investigated. It is concluded that a satisfactory alumina refractory containing up to 90% Al_2O_3 can be obtained from a suitable choice of alunite by calcination to the right temperature and the removal of soluble salts by lixiviation. Alkali fluxes assist in making the alumina refractory dense, but may make it unsuitable in service. However, it is claimed that such impurities are more efficiently received if lower calcination temperatures are employed. High-silica alunite does not offer many possibilities for refractories production. With the high-alumina alunites the by-products assist financially in the economy of production. For an alunite ore to be of economic value, the silica/alumina ratio should not be less than that of mullite.—E. J. D. S.

The Refractory Properties of Alunite. V—Behaviour of Alunite-Alumina in Mixes with Refractory Clays. J. O. Knížek and H. Fetter. (Transactions of the British Ceramic Society, 1950, vol. 49, June, pp. 269–285). The possibility of preparing a series of volume-stable and as nearly as possible homogeneous bodies containing 50 to 80% Al_2O_3 from alunite-Al_2O_3 was investigated. The effects of clay additions were also studied. The results of the investigations indicate that at least two mixes, with 60 and 70% Al_2O_3 respectively, when fired at 1500° C., appear suitable for use in high-alumina refractories. The 80% alumina mixes were not entirely satisfactory because of their tendency to over-fire. Corundum and mullite were formed in mixes with 50 and 60% Al_2O_3, whereas only corundum was identified in bodies with a higher alumina content. The firing characteristics and composition of the clay appeared to affect considerably the mineralogical transformations in the bodies during firing and the more refractory and less nitrifiable clay seemed to favour mullite formation. Low values were obtained for the indices of refraction of the bodies, and the theory is advanced that the glass formed during firing obscured the true optical character of the α-Al_2O_3.—E. J. D. S.

Iron and Steel Plant Refractories. E. B. Guenther. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 100–101, 135). There is a marked trend toward the use of harder burned brick of one quality in all sections of the blast-furnace lining. The advantages which may result from the use of hard-burned super-duty fireclay brick are being explored. In basic open-hearth steel practice super-duty silica brick is becoming more extensively used. The number of furnaces operating with basic ends is increasing.—J. P. S.

Carbon as a Structural Material. A. E. Williams. (Mechanical World, 1950, vol. 128, Aug. 4, pp. 99–101). The manufacture of carbon materials is reviewed with special reference to Delanium, its physical properties, and application in chemical engineering. The use of carbon as a refractory in the blast-furnace is described.—J. W. P.

The Preparation of Carbon for the Manufacture of Electrodes. H. G. Graham and L. D. Schmidt. (Journal du Four Electrique, 1950, May–June, pp. 75–78). The authors present information on the methods adopted in Germany today. The first step in the manufacture is the selection of a coal having a low ash content or containing pyrites, which can be removed by washing. Primary concentration is carried out by hand picking or jig washing. The crude material is then crushed finely and subjected to froth-flotation treatment. Two industrial firms also employ chemical treatment with acid and caustic soda to obtain carbon of sufficient purity for special purposes; the additional expense is stated to be justified. It is necessary to dry the cleaned coal after flotation before the chemical treatment. The methods adopted are described.
B. G. B.

Contribution to the Study of Refractory Wear in Tap Holes. S. Descovich and F. Savioli. (Metallurgia Italiana, 1950, vol. 42, Aug.–Sept., pp. 309–311). A theoretical study is made of the widening of tap holes during the tapping of steel. Consideration is given to the fact that the refractory, at tapping temperature, must be likened to a liquid of high viscosity in contact with a liquid of much lower viscosity. This hypothesis leads to an equation concerning the effects of the dragging action of a flowing liquid in contact with a highly viscous surface, the viscosity of which varies with the distance from the refractory face. Some practical examples are given which confirm the theory.—M. D. J. B.

The Use of Quartzite in Open-Hearth Port Construction. A. Scortecci, A. Polazzi, and F. Savioli. (Metallurgia Italiana, 1950, vol. 42, Aug.–Sept., pp. 297–298). A description is given of the use of quartzite in the parts of a 50-ton open-hearth furnace. Details are also given of the construction and operation of the furnace.—M. D. J. B.

Preparation and Application of Refractory Concrete. A. Nierenski. (Przeglad Techniczny, 1950, July–Aug., pp. 374–379). (In Polish). Compositions, methods of preparation, and uses of refractory concretes suitable for temperatures up to 1400° C. are described.—V. G.

Refractories in the Foundry. W. F. Ford and J. R. Rait. (Institute of British Foundrymen: Foundry Trade Journal, 1950, vol. 88, May 11, pp. 497–502). The reasons why monolithic silicon–clay linings give equally as good service as silica brick linings are examined. The refractory properties of seven proprietary converter linings are discussed. The effect of the addition of alumina on the melting point of silica is covered, and consideration is given to the SiO_2–FeO binary and the SiO_2–Al_2O_3–FeO ternary thermal equilibrium diagrams, from which it appears that slag resistance decreases with increase in alumina content. The use of siliceous clay as a bonding agent will reduce the tendency for the grog grains to be leached out of a molten matrix. Grain-size distribution is examined, and the importance of high density and correct proportions of coarse, medium, and fine grains are detailed. Low water content is necessary to prevent 'bursting'; the percentage of cristobalite in the mixture must be limited. In addition to determination of alumina content, constitution,

and grading, routine American Foundrymen's Society tests for moisture content and green and dry strengths will provide adequate control.—J. E. W.

Refractory Products of the Grochow Magnesite. W. Kisielow. (Hutnik, 1950, vol. 17, Jan–Feb., pp. 10–17). [In Polish]. The usefulness of the refractory products from Grochow magnesite is reviewed. The chemical analysis and refractory properties indicate that this magnesite deposit is of appreciable value to industry.—W. J. W.

Proper Coke Oven Refractories Reduce Overhead Costs. R. P. Heuer and C. E. Grigsby. (Steel, 1950, vol. 126, May 29, pp. 64–68; June 5, pp. 98–104). The author gives a short history of the development of the modern coke oven and points out that a battery is one of the most complicated and costly of refractory structures. The correct types of refractory material to be used to avoid too frequent oven repairs are discussed. Silica is used to resist vitrification, shrinkage, load, and abrasion at the highest temperatures and fireclay to resist thermal shock below red heat.—A. M. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast Furnace and Ore Preparation Plant. (Metallurgia, 1950, vol. 42, July, pp. 75–77). The trends in design of modern blast-furnaces in Great Britain are discussed. The factors affecting output are mentioned, including the hearth diameter, which appears to offer increased output with larger hearths up to a maximum limit of about 28 ft. in dia. The production increase claimed for high top-pressure practice is mentioned. The new plant being installed at several iron and steel works is described with reference to their expected outputs and the steps being taken to convert old plant to modern requirements.—J. J.

Saving Time in Rebuilding Blast Furnaces. T. A. Lewis. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 113–115). The author describes methods introduced into the Bethlehem Steel Co. which have contributed to a considerable saving of time in the rebuilding of blast-furnaces. The uses of mine loading machinery, bulldozers, and dozer-shovels are discussed. It is estimated that two days and 1000 man-hours per furnace relining can be saved by these means. Motor trucks and pallets are used in the handling of bricks as well as elevators to raise bricks to the top of the furnace. Internal steel scaffolding has replaced timber. The old method of blasting salamanders has been abandoned in favour of dropping a 10-ton ball. Sand-blasting is adopted for cleaning hot-blast checkers while in place. Lastly the author stresses the need for careful planning of work and co-ordination in the repair crews.—M. D. J. B.

On the Reduction Velocities of Iron Oxides. E. P. Tamiyevskaya, G. I. Chufarov, and V. K. Antonov. (Bányászati és Kohászati Lapok, 1950, vol. 5, Oct., pp. 579–583). [In Hungarian]. This paper is a translation of a paper published in the April 1950 issue of the Bulletin of the Russian Academy of Science. The authors investigated the reduction velocities of Fe_2O_3, Fe_3O_4, and FeO for certain determined surface areas. They also determined the oxygen pressures corresponding to the dissociations at certain reduction velocities. The preparation of the specimens and the test procedure are described and the results are given in tables and graphs. The authors draw the following conclusions: (1) Thermodynamical calculations confirm that at temperatures between 900° and 1200° K. the equilibrium oxygen pressure during dissociation is about 10^{10} times greater for Fe_2O_3 than for FeO. (2) In spite of the large differences as regards dissociation conditions, the reduction velocities of the three oxides when reduced with hydrogen and for equal surface areas are about equal; the corresponding activation energies are 13·5 to 16·5 kg.cal./mol. (3) The relation between the reduction velocity and the hydrogen pressure is not linear; removal of oxygen from the solid phase lattice structure follows laws during dissociation which are different from those during reduction. (4) The adsorbtion-catalytic character of the reduction process has been confirmed. (5) The relation between the reduction speed and the hydrogen pressure was the same for the three oxides tested.—E. G.

Tremendous Volume of Compressed Air Required to Produce Steel. (Air and Gas Institute: Blast Furnace and Steel Plant, 1950, vol. 38, Mar., pp. 348–349). The rôle of air in the production of steel is discussed and emphasized. Data obtained from the Republic Steel Corp., Cleveland, Ohio, are used to point out the vast quantity of air necessary to the steel industry.—J. P. S.

Blast Furnace and Blowing Room Emergency Signal Systems. R. H. White. (Blast Furnace and Steel Plant, 1950, vol. 38, Apr., pp. 419–422). The author presents the recommendations of a committee to prevent the occurrence of explosions or serious fires in cold-blast mains. Details are given of a signal system for conveying wind-change requests direct to the blast source; a low-pressure alarm; a high-blast-temperature alarm, and an intercommunication system.

J. P. S.

Pig Iron Production in the Low-Shaft Blast-Furnace by the Humboldt Carbonization Smelting Process. F. Jaeger. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 711–712). The process, in which briquetted mixtures of iron ore and coal are heated in the upper part of the shaft of a low-shaft furnace to carbonize the coal and the resulting coke–ore mixture smelted in the lower portion, is described. The advantages of this process for treating fine ores without the need for sintering and for utilizing low-grade non-coking coals are discussed.

J. P.

The Theory, Equipment and Operation of Lime Injection through the Tuyeres of a Blast Furnace. G. Steudel. (Blast Furnace and Steel Plant, 1950, vol. 38, July, pp. 775–778). The author maintains that the introduction of flux through the tuyeres offers a solution to the problem of uniform iron quality through the immediate control of hearth-slag composition. The adjustment of bosh slag to a lower basicity and viscosity range offers possibilities of a more uniform and possibly higher wind rate with an accompanying increase in iron production. A reduction in coke consumption is anticipated. The injection equipment and its operation are discussed and a schematic drawing is given of the equipment as applied to a 1000-ton furnace with 16 tuyeres.—J. P. S.

Possible Increase in the Consumption of Carbonates in the Blast-Furnace and the Increase in Production Thus Obtainable. F. Millan. (Dyna, 1950, vol. 25, Oct., pp. 343–361). [In Spanish]. The main advantages of iron ore beneficiation in the Biscay-Santander region where 80% of the Biscayan ores are carbonates are: Increased output of pig iron; decreased coke consumption; possibility of using higher proportions of carbonates; lower sulphur content in the iron; less flue dust made and the possibility of using that which is made; more uniform working of the furnace and the avoidance of scaffolds. The author describes a series of trials made over a number of years at the Altos Hornos de Vizcaya works on the screening, crushing, and sintering of Biscayan and Santander ores. The trials were divided into six groups: (1) Bilbao carbonates; (2 Bilbao carbonates and washed Dicido; (3) Bilbao carbonates, Dicido, and flue dust; (4) Bilbao carbonate, Dicido, flue dust, and sintering residues; (5) pyrites and ore; and (6) Rubio ores. The raw carbonates sintered badly, using much coke and taking a long time. Calcined carbonates sintered fairly well, and better still, when mixed with siliceous ores, *e.g.*, with Dicido from Santander.

The conclusions are: (1) It is possible to increase the proportion of calcined carbonates in the burden from 33 to 66% and, if required, to 100%. All the necessary ore preparation plant can be made in Spain, except the fans, and crushing and sintering plant; (2) pig iron output could be increased 22%; (3) this solution to the problem of using more carbonates in the burden would also permit the utilization of other by-products such as pyrites residues from sulphuric acid manufacture (about 120,000 tons per year).—R. S.

Evaluation of Blast-Furnace Operational Results. H. Kegel. (Stahl und Eisen, 1950, vol. 70, Aug. 17, pp. 733–740). The coke consumption of three blast-furnaces over a period of five months in 1948 was higher than was expected from the results reported by F. Wesemann. This was attributed to the effect of low blast temperature. A considerable reduction in coke consumption can be achieved by avoiding or restricting channelling in the burden. The larger the proportion of fine ore in the burden the lower is the critical blast velocity to induce channelling. It follows that reduced consumption is made possible by sintering the fines, by adequate mixing of the burden, by reduction of the diameter of the tuyeres, and by increasing the blast pressure so as to achieve a deeper penetration and more uniform driving. Experiments on models have shown that improvements in coke quality as well

as high blast temperatures and suppression of channelling leads to low coke consumption. It was confirmed that blast-furnace gas temperature increases and indirect reduction decreases with increasing coke charging rates; hence indirect reduction increases with rising gas temperatures. With one furnace there was a high indirect reduction and a low coke consumption in spite of marked channelling. It was therefore concluded that channelling has a stronger influence on gas temperature than on indirect reduction. Continuous recording of blast pressures and temperatures, and gas temperatures and analysis can furnish data which will indicate ways of reducing coke consumption and give an insight into the processes in the furnace.—J. P.

British Iron and Steel Works Plant and Practice (5). Automatic Control of Iron and Steel Works' Operations. R. A. West. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 18, pp. 357–360). The author reviews some of the wide variety of controls used in the iron and steel industry in order to economize in manpower and to ensure correct sequence of movements. Special reference is made to blast-furnace skip-hoist control as an outstanding example of automatic sequence control.—G. F.

TREATMENT AND USE OF SLAGS

Conditioning Blast Furnace Slag for Commercial Use. F. Osborne. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 252–263). Some of the commercial uses of blast-furnace slag, and the conditioning processes through which it is put, are described.—G. F.

PRODUCTION OF WROUGHT IRON

Production of Wrought Iron. C. R. Fondersmith and E. B. Story. (Steel, 1950, vol. 126, Mar. 6, pp. 92–102). The authors trace the development of the wrought iron industry from prehistoric times up to the present day. In recent years improved rolling technique has made possible an equalization of the normal ultimate strength and ductility in the rolling and transverse directions. Experiments are being carried out with alloys containing 1·5 to 3% of nickel which can increase the tensile strength to 60,000 lb./sq. in. and the yield point to 45,000 lb./sq. in.—A. M. F.

PRODUCTION OF STEEL

Fontana Plant Increases Tonnage Output and Diversifies Products. W. A. Green. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 71–76). The Fontana works is being expanded by the following plant. A second blast-furnace, 45 coke ovens, a seventh open-hearth furnace, two soaking pits, a second slab furnace, an 86-in. hot strip mill, and an electric weld pipe mill. General constructional and operational details of the plant additions are given together with details of a considerable quantity of auxiliary equipment. Changes in plant layout are discussed.—J. P. S.

Steelmaking and Tube Production at the Clydesdale Works of Stewarts and Lloyds Limited. (Iron and Coal Trades Review, 1950, vol. 161, Dec. 1, pp. 819–823). The Clydesdale Works of Stewarts and Lloyds, Ltd., produces seamless tubes. A new melting shop has been built, with an ingot capacity of 150,000 tons/annum, the tube plant requiring between 50,000 and 100,000 ingot tons/annum depending on the size of tube being made. The melting shop and steelmaking practice are described and special features in tube steel manufacture are indicated. The tube plant consists of six main sections: (1) Ingot reheating furnace; (2) hydraulic piercer; (3) rotary elongator; (4) Pilger mill; (5) sizing mill; and (6) finishing department. Each section is described in some detail.—G. F.

Metallurgical Aspects of Steel Manufacturing in the West. J. H. Shank. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 318–327). The author discusses some of the metallurgical factors peculiar to the manufacture of steel in the Western areas of U.S.A., dealing briefly with the sources and properties of the raw materials, the type of scrap used, liquid fuels, the rolling mills, and marketing problems. Mention is made of the special problems encountered regarding the supply and conservation of water.—G. F.

A Summary of Accomplishments to Improve Surface Quality of Steel. S. C. Faddis. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 340–356). The author discusses some of the major developments which have contributed to the improvement of the surface quality of steel. The open-hearth practices considered include immersion pyrometry, the effect of manganese in counteracting sulphur, the effect of different nozzle sizes, the use of ingot shaking machines, the effect of mould dressings, and the use of corrugated moulds. Blooming-mill and hot-rolling practices, and methods of surface dressing, are also considered. It is emphasized that means of further improving surface quality should still be sought in view of the increasing strictness of consumer requirements.—G. F.

Innovations and Developments in The Iron and Steel Industry. G. Bulle. (Metalurgia y Electricidad, 1950, vol. 14, Nov., pp. 24–27). [In Spanish]. The author surveys the problems of ore beneficiation; direct reduction; use of oxygen; continuous casting; and furnace design. The future open-hearth furnace would conform more to the hearth designs of the electric furnace. Longitudinal hearths would not be necessary with the oxygenated short flame. Large and complex recuperators would disappear and side doors would give place to overhead charging as in arc furnaces. In electric furnaces melting would be accelerated by using electric arcs and oil burners with oxygen. Oxygen would be used in the basic-Bessemer process to double output and to enable up to 30% of scrap to be charged. Nitrogen would be eliminated. Steam or carbon dioxide would be used to cool the bath. The addition of liquid lime, melted separately, would enable 15% more scrap to be charged in the converter and make possible the production of high-carbon steels.—R. S.

Some Aspects of Melting Shop Management. G. R. Bashforth. (British Steelmaker, 1950, vol. 16, July, pp. 368–374; Aug., pp. 408–420; Sept., pp. 450–455). The author first discusses the organization of a steelworks and then considers the fundamental duties of the melting shop manager. The subject of quality control is reviewed with special reference to carbon control, and factors affecting steel output are discussed, including furnace design, fettling practice, casting and charging facilities, qualities of the raw materials, and chemical control. The author finally discusses the melting-shop managers' responsibilities for staff organization and personnel relations, and stresses the importance of maintaining good labour relationships by personal example and through the medium of works committees.—G. F.

Tool Steels. D. J. Giles and F. B. Foley. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 80–89). The manufacture of carbon and high-speed tool steels is discussed in general terms, and brief reference is made to the methods of heat-treatment. Some of the differences encountered in tool-steel manufacture, as compared with the tonnage steel industry, are pointed out.—G. F.

The Acid Bessemer Process in the Manufacture of Pipe. E. G. Price. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 111–125). The application of the bottom-blown acid Bessemer process to tube production is discussed. A brief description of the steelmaking process is given, and the properties and applications of seamless tubes of killed and Bessemer steel, and welded tubes of capped acid Bessemer steel are described and compared. The properties of the seamless tube are shown to be equivalent and in some cases superior to those of open-hearth steel tube.—G. F.

The Use of an Integrating Flow Meter for Studying the Blowing of Basic Converters. M. P. Newby. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 11, pp. 301–304). A brief description is given of investigations made at the Sencille-Maubeuge and the Micheville steelworks into the blowing rate of basic converters, using an integrating flow which records the blast rate as a function of the total quantity of air blown. The results obtained at the two works are compared with each other and with the results of earlier trials at the Homécourt works. A time saving of 1–3 min. was obtained, but it is shown that, although it is fundamentally sound to blow a charge at a rate determined by the total quantity of air already used, the peculiarities of each charge due to such factors as composition and temperature preclude the automatic following of an ideal blowing curve. It is probable that the best use of the instrument is to indicate approximately the permissible blast rate, final adjustment being made as a result of observation.—G. F.

Steelmaking by the Basic Process. V. S. Swaminathan. (Metallurgia, 1950, vol. 41, Apr., pp. 297–300). A description is given, on the occasion of the centenary of the birth of Sidney Gilchrist Thomas, of his life and achievements, together with the results that have accrued from his studies after his death. The fundamental importance of the consequences of being able to utilize phosphoric iron ores for steelmaking and the value of the basic slag fertilizers from the by-products are stressed. The extension of basic linings to metallurgical processes in the copper and nickel industries is also mentioned.—J. J.

Blowing of Basic-Bessemer Iron with Bessemer Slag. W. Geller. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 707–711). Experiments have been conducted on the blowing of iron with basic-Bessemer slag. In the main experiments, slag was removed when the phosphorus content of the iron was 0·5–1·0% and the final blow was carried out with lime. The most important findings were that in a slag in equilibrium with an iron containing 0·5–1·0% phosphorus, there is a definite relationship between the iron and free lime contents of the slag. With basic slags, the iron content is constant at about 3%, but when the free lime becomes less than 0%, there is a rapid and regular increase in the iron content. The essential reducing agent in basic slags is the phosphorus. Silicon acts as a reducing agent only when the slag remains liquid during the early stages of blowing. An example is given in which, by blowing an iron (3·5% C, 2% P, 1% Mn, 0·5% Si) down to 0·5–1·0% phosphorus with a basic-Bessemer slag and then reducing the phosphorus to 0·05% by blowing with lime, there is a saving of 20–25% lime, a reduction in iron loss of about 70%, an increase in the P_2O_5 content of the slag of 6% and a reduction in slag bulk of some 21–23%. As a result of the need for an intermediate slag removal there is a loss of heat and the process takes somewhat longer. The loss of manganese is somewhat greater than in normal blowing.—J. P.

Development in Bessemer Steelmaking since 1940. H. K. Work. (Metal Progress, 1950, vol. 58, Oct., pp. 519–522). Reasons for the decline in Bessemer steel production are linked mainly with the high phosphorus and nitrogen contents that are inherent. However, in periods of high production economic factors favour the process, and in the past decade there have been the following advances: Improved application of converter steel, dephosphorization, aluminium killing, side blowing, and use of oxygen in the blast. The author suggests that side blowing in particular may arrest the decline.—E. T. L.

Production of Steels in the Basic-Bessemer Converter. D. Iturrioz. (Metalurgia y Electricidad, 1950, vol. 14, Apr., pp. 24–26; May, pp. 23–25; June, pp. 37–39). [In Spanish]. Some details are given of the Perrin-Girod slag process of rapid dephosphorization. Analyses of German basic-Bessemer steels for railways and of sheets for tinplate are given. The article discusses further successful applications of aluminium and silicon-killed low-nitrogen basic-Bessemer steels where these have had to replace open-hearth steels. Recent improvements and research include temperature measurement; use of oxygen; the Girardet process for dephosphorizing iron without decarburizing it; use of carbon monoxide in the blast; and the Mons Polytechnic work on the Hamborn process for the production of low-phosphorus and low-nitrogen Bessemer steels—R. S.

Quality Control in the Manufacture of Basic Steels. H. C. Swett. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 263–271). The methods of quality control in use in the manufacture of basic open-hearth and electric steels at the works of the Bethlehem Pacific Coast Steel Corp., are briefly outlined. Consideration is given to the raw material and scrap requirements and to the controls employed in the steelmaking and rolling practice. The inspection procedure is described and reference is made to the importance of the laboratories in establishing good quality control.—G. F.

The Control of the Basicity of Open-Hearth Slag from the Appearance of the Solidified Pancake Sample. J. Zieba. (Hutnik, 1950, vol. 17, July–Aug., pp. 196–204). [In Polish]. The method of determination of slag basicity from the appearance of the surface of solidified slag was tested on 106 samples in the basicity range from 1·3 to about 4·8. The results showed that this method of control is satisfactory, particularly when basicity is below 3.—V. G.

Ionic Theory of Slag–Metal Equilibria. Part I—Derivation of the Fundamental Relationships. Part II—Applications to the Basic Open-Hearth Process. P. Herasymenko and G. E. Speight. (Journal of The Iron and Steel Institute, 1950, vol. 166, Nov., pp. 169–183; Dec., pp. 289–303). In Part I the equilibrium positions of the principal slag–metal reactions are derived from the laboratory investigations of Chipman, Quarrell, Oelsen, and their co-workers, assuming the ionic structure of slags. The advantage of this theory is shown to be that the number of slag constituents sufficient to describe the physico-chemical behaviour of basic slags is considerably smaller than in the theories assuming the presence of oxide molecules and their compounds.

The relationships between the total number of ions, N, or the ionic fraction of oxygen ions, O'', and the sum of acids, Σa (where $\Sigma a = SiO_2 + 0{\cdot}634P_2O_5 + 0{\cdot}90Al_2O_3$ expressed in percentage weights) can be represented by empirical curves. Using these relationships, the equilibrium ratios derived in Part I can be expressed as nomograms for the calculation of the oxygen content of liquid steel and of the desulphurization ratio from the slag analysis.

Oxygen content of the basic steel is a function of the content of FeO and of the sum of acids, Σa. It depends also on temperature and, especially, on the carbon content, because the activity coefficient of oxygen increases strongly with increasing carbon content. The analytically determined oxygen contents for a series of experiments made by the authors agree, within the limits of experimental errors, with the oxygen contents calculated from the slag analysis and corrected for the effect of temperature and of carbon. The desulphurization ratio (S)/[S] is a function of the content of FeO and of the sum of acids, Σa, and is not perceptibly influenced by temperature and carbon content.

The equilibrium between the trivalent and bivalent forms of iron in slag and liquid steel has been examined empirically. The ratio Fe_2O_3/FeO is found to be a function of the content of CaO and of the sum of acids, Σa, both for laboratory slags melted under equilibrium conditions and for basic open-hearth slags. Somewhat lower Fe_2O_3 contents and somewhat higher FeO contents in the open-hearth slags—as compared with laboratory slags of similar composition—are caused by analytical procedure (partial reduction of Fe_2O_3 by hydrogen and hydrogen sulphide when dissolving in hydrochloric acid). The slag in the open-hearth furnace can therefore be regarded as being practically in equilibrium with metal and very far from equilibrium with the furnace gases.

For the estimation of oxygen content and of the desulphurization ratio, the analytical content of FeO can be used without impairing substantially the accuracy of the results.

The equilibrium constant of the phosphorus reaction is more sensitive to variations in the activity of FeO and oxygen produced by small amounts of fluoride in basic slag; a displacement of equilibria is also possible by the formation of complexes between phosphate and fluoride ions. A comparison of the data shows that the dephosphorization ratio for the open-hearth process is higher than that for laboratory melts without fluoride ions in the slag. A further quantitative investigation of the effect of fluoride ions on the phosphorus equilibria is necessary to establish the exact relationships which can be applied to practical steelmaking.

The Thermodynamics of Substances of Interest in Iron and Steel Making. II—Compounds between Oxides. F. D. Richardson, J. H. E. Jeffes, and G. Withers. (Journal of The Iron and Steel Institute, 1950, vol. 166, Nov., pp. 213–234, 245). Part I of this series reviewed thermodynamic data relating to oxides (*see* Journ. I. and S.I., 1948, vol. 160, p. 261). In this part a survey is made of the thermal and equilibrium data at present available for compounds between oxides of interest in iron and steel making. The standard free energies of formation of these compounds from their component oxides are calculated up to 2000° C., and the results are plotted on free-energy/temperature diagrams. Equations and the sources of the data are given for each compound, and limits of accuracy are proposed. The standard free energies of formation vary linearly with temperature within the limits of accuracy of the data available. The application of these diagrams to slag and similar problems is discussed.

Cold Charge Practice in Open-Hearth Operations. O. A. Kresse. (Regional Technical Meetings of American Iron and

Steel Institute, 1949, pp. 302–306). The production of a typical cold-metal heat at the Torrance Works of Columbia Steel Co. is briefly described. Consideration is given to the constitution of the charge and the methods of quality control, and the special requirements of heats for sheet products are discussed.—G. F.

Influence of Melting Conditions on the Hardenability of Unalloyed Open-Hearth Steel with 0·4–1·0% C. M. Hauck and W. Eilender. (Stahl und Eisen, 1950, vol. 70, Aug. 3, pp. 689–697). An investigation was carried out on three furnaces (10, 12, and 22 tons) into the influence of chemical composition, the steelmaking process, and furnace construction on the susceptibility to overheating and hardening of unalloyed open-hearth steel with 0·4–1·0% C. No correlation was found between the hardenability and the final oxygen content or the McQuaid-Ehn grain size of the finished heat. On the contrary, it appeared that the best material was produced when the oxygen content rose progressively from a low value at melt-down up to tapping time. The temperature during the heat played a major part in affecting hardenability. It was shown that the best results were obtained when the temperature of the bath was brought up slowly from melting to tapping temperature and then the steel quickly teemed. In order to attain these conditions, the furnace construction should be such that the carbon drop can be regulated during this temperature rise. It is suggested that these experiments show that it is not the final composition but the way the steel is made, and thus the nature of nuclei, which determine the susceptibility to overheating and the hardenability.—J. P.

Duplex Processes in Steel Manufacture. D. Iturrioz. (Metalurgia y Electricidad, 1950, vol. 14, Aug., pp. 25–27; Oct., pp. 27–30). [In Spanish]. Some general remarks are made on acid-Bessemer/basic-open-hearth duplexing in North America, using hot metal, and German duplexing, using scrap and stahleisen with basic-Bessemer/basic-open-hearth or electric arc furnace duplexing. The Corby basic-Bessemer/electric duplexing is briefly reviewed. Data in connection with the acid-Bessemer/basic electric duplexing trials at Workington during the war, are given. The use of the Perrin process as a duplex process is instanced in the case of The Tata Iron and Steel Co. who used a basic-lined converter for desiliconizing and decarburizing, and dephosphorized by pouring from a fixed height into a ladle containing ready made slag which was very fluid, highly basic, and oxidizing. This slag was made in an open-hearth furnace manufacturing low-carbon rimming steel. Further modifications of the Perrin process were used in France during the war. In these cases deoxidizing and desulphurizing slags were made from mixtures of lime and alumina, previously made in a small electric furnace.—R. S.

Experiments on Gaseous Mixing in Open-Hearth Furnace Models. Part II—Semi-Venturi Designs. R. D. Collins and J. D. Tyler. (Journal of The Iron and Steel Institute, 1950, vol. 166, Nov., pp. 235–245). The technique of using models to determine the degree of mixing (*see* Part I in Journ. I. and S.I., 1949, vol 162, Aug., p. 457) is applied in Part II to a series of modified semi-Venturi designs. The most significant factors are (*a*) size of gas port (multiple ports provide very quick mixing without increased uptake pressures), (*b*) slope of gas port, (*c*) length of gas port, (*d*) distance of throat from gas port, and (*e*) sharpness of throat and knuckle contraction. These affect not only the degree of mixing but also the shape of the mixing pattern. Thus, the slope of the gas port controls stratification, multiple gas ports give high initial rate of mixing, and throat modifications affect the later stages of mixing.

A provisional theory of mixing is developed in which two zones are considered separately, the space occupied by the jet of gas issuing from the gas port, and the remainder of the furnace space. The experimental results are explained on this principle.

Scrap Preparation and Furnace Charging as Related to Cold Metal Open Hearth Shops. W. A. Johnson. (Journal of the West of Scotland Iron and Steel Institute, 1948–49, vol. 56, pp. 145–168). The methods suggested to improve the rate of charging can be divided into three main sections: (1) Alteration of furnace design and charging equipment; (2) improved scrap preparation; and (3) melting scrap in cupolas and adding the liquid metal to the furnace. Possible furnace and charger alterations include: (*a*) Top charging in conjunction with a roof constructed with removable sections; (*b*) a charger with a pan area similar to that of the hearth, for use with a furnace with a detachable front; and (*c*) a long-peel type of charger with a self-contained conveyor for charging the furnace in sections much longer than normal. Methods of scrap preparation considered are magnetic separation of large and small scrap, shearing, and baling to increase bulk density. The economic justification for the substitution of cupola metal for cold-charged materials depends largely on (*a*) the reduction in tap-to-tap time which may be 20% to 50% with 25% to 55% hot metal, and (*b*) whether, as at present, the difference in price between pig iron and scrap exceeds the cost of conversion of scrap into hot metal in the cupola.

P. C. P.

Application and Use of Automatic Controls for Open-Hearth Furnaces. E. Whitehead. (Steel, 1950, vol. 126, Mar. 27, pp. 76–80, 87–92). The two vital factors in the control of open-hearth reactions are considered to be furnace atmosphere and heat. The former requires the control of fuel/air ratio and furnace pressure, the latter can be controlled by measuring the temperature of some part of the bath or furnace, but provision must be made to maintain preheat temperatures in balance by reversal control. The methods and accuracy of control and the principles of operation of regulators are discussed.—A. M. F.

Modification in the Charging of Open-Hearth Furnaces with Cold Pig Iron. G. Répási and G. Janovich. (Bányászati és Kohászati Lapok, 1950, vol. 5, Sept., p. 530). [In Hungarian]. To shorten the charging and melting times charging is started by placing 15 to 20% of the scrap on the hearth and some pig iron on each of the two flame bridges. On top of this is placed the required quantity of lime; charging then proceeds in the usual way. It is claimed that during the experiments the charging time was 1 hr. 40 min. instead of 4 to 6 hr. and the melting time was also shortened from 4 hr. to 2 hr. 5 min.—E. G.

The Thermodynamic Background of Iron and Steelmaking Processes. II—Deoxidation. F. D. Richardson. (Journal of The Iron and Steel Institute, 1950, vol. 166, Oct., pp. 137–146). Part I of this series dealt with the blast-furnace (*see* Journ. I. and S.I., 1949, vol. 163, p. 397). In the present part the thermodynamic principles involved in deoxidation are discussed. A critical survey is made of the thermodynamic data available for solutions of oxygen and alloying elements in liquid iron, and the main deoxidation equilibria are summarized in two diagrams for 1600° C. and 1540° C. The general pattern of the results is discussed in terms of the interaction of dissolved oxygen and dissolved deoxidizer in the liquid metal.

Output of Electric Steel Furnaces with Bath Diameters Greater Than 3600 mm. F. Badenheuer. (Stahl und Eisen, 1950, vol. 70, May 11, pp. 403–409). Typical output figures of individual arc furnaces were ascertained from a number of works and used to give guidance as to the correct weight of charge, the length of slagging and refining periods, etc. as a function of bath diameter. As a result, the participating works were able to show a great increase in output, particularly those using metal from a basic-Bessemer converter. The conditions for obtaining good recovery of chromium additions are described.—J. P.

Increasing the Output of Cold-Charged Electric Arc Steel Furnaces. E. Pakulla. (Stahl und Eisen, 1950, vol. 70, May 25, pp. 445–452). A scrutiny of the logs of 54 electric arc furnaces during several months of 1943 and 1944 has permitted the optimum values of slagging, refining, and tap-to-tap times and output per hour to be defined as a function of charge weight. Since many of the furnaces were not working under these optimum conditions, methods of increasing output were readily indicated. Suitable transformer loadings for various-sized furnaces have been calculated and the power consumption and losses per ton given for different loadings. The extent to which the melting time is prolonged by the increased quantity charged, and the effect of the decreased wall life on production are dealt with in detail.—J. P.

Electric Arc Furnace Steel Quality. R. Sergeson. (Iron and Steel Engineer, 1950, vol. 27, June, pp. 100–103). Electric arc furnaces, both acid and basic, are briefly described and sizes and details of equipment given. The manufacture of rimming, semi-killed and aluminium-killed low-carbon

steels; resulphurized steels; single-slag-process steels for cold drawing and coil springs; and double-slag-process steels are considered as well as aircraft and oil-hardening bearing steels and special, stainless, high-speed, and die steels. Factors influencing the quality of steels including the raw materials, the melting, moulds and pouring, time in moulds, ingots, and rolling are reviewed and tests for determining quality are considered.—M. D. J. B.

Electric Steel Melting. G. A. Wood. (ESC News, 1950, vol. 4, No. 3, pp. 3–8). After presenting data on the quantities of electric furnace steel produced in different countries from 1937 to 1947, and outlining the advantages and disadvantages of the process in England, descriptions are given of arc furnaces and high-frequency induction furnaces operated by the English Steel Corporation. Typical logs of heats and operating data are given.—R. A. R.

Arc Furnace Operation and Equipment. A. R. Oltrogge. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 87–98, 139). A review of the electrical fundamentals of furnace performance is given to serve as a guide to melting shops in analysing the operation of their furnaces. The volt-ampere characteristics of arc furnace circuits are discussed and the method of determining the power (heat) input curve is described. The factors influencing the selection of proper voltage tap and current setting are surveyed. The paper includes a discussion on arc furnace electrical equipment.—J. P. S.

Use of Oxygen in Electric Furnaces. (American Iron and Steel Institute, Sept., 1950, Contributions to the Metallurgy of Steel No. 37). This 'Contribution' contains 20 pages of tables of operating data relating to oxygen practice in connection with electric furnaces at a number of American steelworks. They are divided into 'General Questions,' and the making of (*a*) rimming and semi-killed steel, (*b*) S.A.E. and N.E. steels, and (*c*) stainless steels.—R. A. R.

Acid Operation of an Electric Furnace. E. Sautereau. (Fonderie, 1950, Aug., pp. 2165–2166). Some practical hints are given to an enquirer wishing to use a 30 to 40-cwt. electric furnace. Both Héroult and induction types are considered. Details are given of linings, materials and drying, repairs and current requirements, with brief remarks on slag management and final additions.—R. S.

The Electrical Conductivity of Slags in the Liquid and Solid State. W. A. Fischer and H. vom Ende. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 217–224). A comparatively simple apparatus was used to study the resistance/temperature relationships of wüstite, fluorspar, FeO–SiO_2 slags (up to 36% SiO_2), FeO–SiO_2–CaO slags (CaO/SiO_2 = 0·6 and 7·5–32·0% FeO), and FeO–CaO–Al_2O_3 slags (CaO/Al_2O_3 = 1 and 11·0–29·8% FeO) over the range 200–1400° C. In the molten state every slag had a low resistance, a marked increase being evident below the melting point. Wüstite has a characteristic state of semi-conduction in which electronic transport must predominate; there is no discontinuity at the melting point. Semi-conduction also appears in slags very high in FeO. With low FeO contents, all slags show marked ionic conductance. There are differences in that some slags show unipolar and others show bipolar conductance. Fayalite belongs to the former and fluorspar to the latter group. The formation of new phases within the solid solution range can be detected by conductivity measurements even above the liquidus temperature. Thus there is a break in the curve of a liquid FeO–CaO–Al_2O_3 slag at 16·5 mol-% FeO, and X-ray examination of the quenched slag shows that up to this content of FeO there exists a binary compound $5CaO.3Al_2O_3$. At higher FeO content there is a new compound, probably of a ternary nature.—J. P.

The Oxygen Content of Liquid Iron and the Solubility of Oxygen in Solid Iron. W. A. Fischer and H. v. Ende. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, Sept.–Oct., pp. 297–304). Experiments on iron melted in an induction furnace under ferrous oxide and silica-saturated ferrous oxide slags have shown the validity of the Nernst law for the distribution of oxygen between slag and metal. Deviations from ideal behaviour were found in the case of lime-saturated slags; the relationship L_{FeO} = 0·62 (FeO)/[O] held at the liquidus temperature (1520–1530° C.). This reduced activity of FeO is attributed to the presence of calcium ferrite in the molten slag. It is considered that in lime-saturated slags there is just sufficient ferric oxide to combine with all the lime as $3CaO.Fe_2O_3$. Any iron in excess of this is present as FeO and it is this amount which controls the oxygen content of the metal. No tricalcium ferrite could be found in the solidified slag but only $2CaO.Fe_2O_3$. A study of the inclusions in quenched melts of various oxygen content indicated that the solubility at the solidus temperature (about 1520° C.) is between 0·05 and 0·06%. Qualitative tests have indicated that the solubility decreases with decreasing temperature.—J. P.

Mould Design and Pit Casting: Influence of Metal Flow, Turbulence Losses, Teeming Speed and Ingot Shape. W. L. Kerlie. (Iron and Coal Trades Review, 1950, vol. 161, Aug. 4, pp. 231–242). The author presents a theoretical consideration of factors affecting the casting of steel. The flow of metal from the ladle, the behaviour of the metal in the trumpet and runners, and the rise of metal in the mould are considered, special attention being paid to fluidity, viscosity, and surface tension phenomena, metal head in the ladle, rate of nozzle wear, turbulence losses, and the variations in static level in the mould and trumpet. The author then examines the effect of these factors on the ingot surface and studies the influence of mould design particularly on crack formation. Surface tension is shown to play an important part in the formation of the ingot surface, and in this respect the necessity for absolute cleanliness of the mould surfaces is emphasized. It is considered that the problem of ingot cracking should be met by changes in mould design rather than by reductions in teeming temperature.—G. F.

Distribution of Inclusions in Forged Steel. P. Cattier, C. Dubois, J. Bleton, and P. Bastien. (Société Française de Métallurgie: Metal Treatment and Drop Forging, 1950, vol. 17, Spring Issue, pp. 47–52; Summer Issue, pp. 102–109). Four 6½-ton ingots of a steel containing 0·30% C, 1·6% Ni, and 0·6% Cr, were made by the duplex, basic, and acid processes, two ingots being made by the acid method, but one being cast at a temperature higher than normal. The ingots were all forged down to cylinders 13 in. in dia. by 20 ft. long, homogenized by double heat-treatment, machined to 11¾ in. in dia., quenched in water from 830° C., and tempered at 625° C. The segregation of carbon, sulphur, and oxygen was studied by chemical analysis, and the structural heterogeneity was examined by macro and microscopic methods. The location and distribution of silicate and sulphide inclusions was also studied in detail. The authors show that the sulphide inclusions are found in the most hardened regions (those richest in carbon), whilst the silicates are located in bands of annealed structure, along the axes of the original dendrites, and preferably in the ferrite areas. There are 15 references.—P. M. C.

Factors Contributing to the Cracking of Medium Carbon Silicon-Killed Steel Ingots. J. A. Warchol. (American Institute of Mining and Metallurgical Engineers: Blast-Furnace and Steel Plant, 1950, vol. 38, Feb., pp. 221–222, 224, 253). The metallurgical and mechanical factors affecting the susceptibility of ingots to cracking were investigated. The results indicated an increase in the frequency of cracking for sulphur contents above 0·035%. Cracking was also more prevalent with steel containing 0·35–0·50% of manganese than it was for steel containing 0·07–0·90% of manganese. Other factors found to increase the cracking of ingots were cracked moulds and bottom plates, an increase in teeming speed, an increased metal temperature for given pouring speed, long ingot delivery time and thermal shock due to improper soaking-pit practice. Proposals, based on the results, are made for reducing the number of cracked ingots.—J. P. S.

Steel Compositions and Specifications from the Steel Producers Viewpoint. C. M. Parker. (Society of Automotive Engineers: Blast Furnace and Steel Plant, 1950, vol. 38, Apr., pp. 438–442, 443–468). The author discusses the difficulties which arise for the steel producer as a result of faulty specification by the consumer. Some results obtained by a committee studying carbon steel bars and semifinished products of 'off-heats' attributable to manganese in carbon steels are given. Some of the problems that arise in the control of variability in alloy steelmaking, which have been studied by another committee, are outlined and 'off-heat' data are given in tables. The article ends with a discussion on the selection treatment of raw materials.—J. P. S.

PRODUCTION OF FERRO-ALLOYS

Manganese Research. C. H. Herty, jun. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 202–208). The author briefly discusses the main

functions of manganese in steelmaking and reviews the principal sources and economical use of manganese in view of the increasing present-day requirements. Some of the outstanding research problems are indicated.—G. F.

Applied Electrothermy. A. Amoros. (Metalurgia y Electricidad, 1950, vol. 14, Aug., pp. 28–32). [In Spanish]. The electric furnace is eminently suitable for the manufacture of ferro-alloys involving highly endothermic reactions and enormous concentration of heat in a reduced space. The importance of producing the correct type of slag and of correct mixing of the charge is studied. The physical and chemical functions of slags are explained and the melting points of various silicate, aluminate, and oxide slags are given. Slag viscosity is reviewed and the calculation of basicity indices is explained. Some calculations of charge mixtures for the manufacture of 50% ferrosilicon and for making castings by the direct reduction method are shown.—R. S.

The Reduction of Pyrolusite Ore by Pyrites, Coke, Sulphur Dioxide or by Ferrous Sulphate. M. Perec and K. Pinkas. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 3, pp. 187–195). [In Polish]. A short survey of existing methods of reducing manganese dioxide is given and investigation of reduction of pyrolusite ore by pyrites, coke, sulphur dioxide, and ferrous sulphate is described.—V. G.

FOUNDRY PRACTICE

Progress and Existing Opportunities in the Foundry Field in Brazil. M. Siegel. (Mineração e Metalurgia, 1950, vol. 14, Mar.–Apr., Noticiario, pp. 1–4). [In Portuguese]. Following a brief survey of ferrous and non-ferrous foundries, the author enumerates some developments since 1930, including centrifugally spun pipes, chillcast wheels, special castings for railways, sand, and chill casting of aluminium alloys under pressure. These Brazilian developments are compared with foreign progress in the development of making castings, patterns, cores, and moulds, and in feeding, trimming, and heat-treatment. Immediate opportunities for further research and development in Brazilian foundries are enumerated. R. S.

Rapid Checking of the Dimensions of Castings. J. Poch and S. Z. Plzek. (Kovodělny Průmysl, 1950, May, pp. 74–77). [In Czech]. A rapid method of checking the dimensions of castings is described. The casting is bolted on to a specially designed frame. The scale drawing of the checked part is drawn on perspex or any other solid transparent material and the plate containing this drawing is placed on the frame so that a comparison can easily be made. E. G.

Preparation of Work in the Foundry. E. Lecœuvre and H. Dubois. (Fonderie, 1950, Sept., pp. 2167–2185). Fifteen main responsibilities of the foundry manager are listed. As a concrete example of the co-ordination in the 'preparation of work,' the manufacture of diesel engine frames is described in detail, followed by an analysis of all the operations of pattern-making, core-making, mould-making, and trimming. Time study graphs and diagrams are given.—R. S.

Modern Foundry Practice. C. S. Johnson. (Journal of the Institution of Production Engineers, 1950, vol. 29, July, pp. 311–332). Methods of technical control of mechanized foundries are reviewed with particular reference to the production of iron castings. The factors which control the production of high quality castings at economical prices are: (1) Overall efficiency; (2) pattern and moulding box equipment; (3) metallurgical control; (4) inspection; and (5) supervision and maintenance of plant. These factors are discussed from the viewpoint of an engineer.—J. W. P.

The B.C.I.R.A.'s Balanced Blast Cupola. W. T. Main. (Australian Foundry Trade Journal, 1950, vol. 2, Sept., pp. 14–21). The development, advantages, and operation of the balanced blast cupola are described. Greater thermal efficiency, less bridging on extended runs, and a hot metal of fairly even temperature are obtained. The use of a special draining hole, through which the last traces of iron and slag are removed, renders the subsequent removal of the bottom dump a much easier operation.—J. E. W.

Slagging Practice—A Means of Cupola Control. T. F. Hart. (Australian Foundry Trade Journal, 1950, vol. 1, May, pp. 10–12). With no fluxing agents a cupola slag is very viscous, and leads to poor blast distribution, low melting rate, low tapping temperature, bridging, and an increased coke consumption. Correct fluxing will rectify all such disadvantages, and also clean the metal by forming a blanket over the well metal, which will trap impurities and desulphurize it. The fluxing agent principally used is lime, but dolomite, fluorspar, and sodium carbonate are also employed, the latter two essentially to promote fluidity. Normally, for Australian cokes the weight of lime required is approximately 25% of that of the coke charge. It is good practice to add two such charges direct on the bed coke, to promote the early formation of a slag blanket. The slag to be aimed at should have an analysis of SiO_2 35–45%, Al_2O_3 10–20%, lime-magnesia 30–40%, Fe 5–8%, and MnO 1–4%. Maximum desulphurization is obtained with a silica content of 35–40%.—J. E. W.

Sodium Carbonate Process for Metal Refining. W. Dummett. (Australian Foundry Trade Journal, 1950, vol. 1, July, pp. 3–7; Aug., pp. 3–6). The author reviews the Imperial Chemical Industries' publication "Sodium Carbonate for Metal Refining." When considering the mechanism of the sodium carbonate process of metal refining, three simple chemical reactions are concerned: (1) The thermal decomposition of sodium carbonate; (2) the reaction between sodium carbonate and certain metallic sulphides; and (3) the reaction between sodium carbonate and silica. There are two methods used for the addition of sodium carbonate: (1) Tapping the molten metal on to the granular sodium carbonate in the ladle; and (2) adding fused sodium carbonate to the cupola charge. Recommended methods for specific purposes, such as the production of centrifugal castings, and the melting of cast-iron borings in the cupola are detailed. The use of 0·5% fused sodium carbonate blocks in the cupola charge reduces small surface porosity in light castings which have subsequently to be enamelled.—J. E. W.

Desulphurization of Cast Iron with Carbonate of Soda. J. Guillamon. (Fonderie, 1950, Sept., pp. 2186–2187). The treatment can be carried out directly in the ladle or in the chute between the cupola and the mixer. Details of procedure and quantities are given for sodium-carbonate desulphurization in ladles of over 500 kg. capacity, and for desulphurization with a mixture of sodium and calcium carbonates (for smaller lots). The two methods are compared. The 'double ladle' method is described, whereby powdered carbonate of soda is placed in a dolomite-lined ladle, the iron being run in from the cupola and the contents then poured into a second basic-lined ladle where the reaction continues. An 80–90% desulphurization is achieved. Desulphurization in the receiver (where the cupola has an output higher than 8 tons/hr. is also described. It is not necessary to thicken the slag with lime. The degree of desulphurization is a function of the percentage addition of carbonate of soda, thus:

Na_2CO_3, %	Desulphurization, %
0·25	15
0·50	40
1·00	60

and also of the duration of the reaction.—R. S.

Basic-Lined Cupola for Iron Melting. S. F. Carter. (American Foundrymen's Society, May, 1950, Preprint No. 50-50). The successful production of iron in a 23-in. cupola lined with dead-burned magnesite brick and laid with magnesite mortar is described. Dolomite patching was found to be inferior to magnesite, whilst magnesite plus 10% bentonite was almost as good. Magnesite consumption was less than one third that of clay brick on 9-hr. production melts and in some instances less than one fifth for very severe melting conditions. From 0·10 to 0·32% P was removed in the cupola from 0·30 to 0·80% P irons with a highly basic slag and several oxidizing treatments, the cheapest of which resulted from the use of a low coke ratio. Removal of all the silicon was not necessary for dephosphorization at such phosphorus levels, but much lower silicon contents were required than usually present in grey-iron compositions. The use of manganese ore permitted the retention of a higher carbon content in the melt; the higher the manganese content the lower the sulphur and the better the slag condition. From 0·020 to 0·040% lower sulphur was obtained from charges having the usual sulphur content, and as much as 0·100% S lower at high sulphur levels. Further decreases in sulphur were found to require lower FeO

in the slag as well as higher basicity, necessitating stronger reducing conditions than in conventional practice. The use of sodium carbonate is also discussed. Greater desulphurization was achieved by using lump commercial calcium carbide in the cupola charge. Increased carbon pick-up was caused thereby and provided, indirectly, a second means of lowering the phosphorus content, *viz.* a higher proportion of steel in the charge. The investigations described are considered to make possible the production of iron, the graphitic carbon of which is subsequently to be nodulized.—E. J. D. S.

Metal Losses in an Iron Foundry. G. Daveau. (Fonderie, 1950, Aug., pp. 2163–2164). The following items contribute to 'metal losses' *i.e.*, difference in weight between charge and metal made: (1) Sand adhering to pigs from sand-cast pigs (should not exceed 1% of the weight of raw materials charged); (2) non-metallics or easily oxidizable metals such as zinc, which are lost in melting; (3) oxidation losses, especially silicon and manganese; (4) projection losses in the form of droplets during casting; (5) loss of iron in the slag; and (6) losses during the dressing and stripping of the castings.—R. S.

Manufacture of Grate Bars. J. Guillamon. (Fonderie, 1950, July, pp. 2129–2130). Pearlitic iron can be used for temperatures up to 500° C., manganese iron or medium chromium iron for 500–600° C. Instructions for charge mixtures and details of final analyses obtainable are given for these three types. Hints on melting control and optimum tuyere sections are given.—R. S.

Manufacture of Castings in Extra Hard Cast Iron. G. Joly. (Fonderie, 1950, Jan., p. 1916). Some brief notes are given on the manufacture of white iron castings possessing great wear and impact resistance. The analysis was total carbon 3·50–4·00%, Si 0·80–1·00%, Mn 0·50–0·08%, S 0·10%, P 0·30%, Ni 2·0–3·0, and Cr 1·50–2·00%. For alloy cast iron, a pig of suitable composition is simply remelted. For ordinary white iron, ordinary hematite iron, mild steel, and scrap are used. An average mixture is mild steel 45%, hematite iron 15%, scrap 40%. The hematite contains Si 2·50–3·00%, Mn 0·60–1·00%, and P 0·08–0·10%. Thin pieces of oxidized strips and drillings must not be used. Sufficient feeder heads must be allowed to deal with the considerable shrinkage (up to 18 mm./m.). The zone of fusion in the cupola must be as high as possible which necessitates a fairly considerable quantity of coke and air. Coke must be charged to about 1 m. above tuyere level and the percentage of coke in the charge must be 14 to 15.—R. S.

On the Crystallization of Cast Iron with Nodular Graphite. K. P. Bunin and G. I. Ivantsov. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 72, No. 6, pp. 1051–1053). The crystallization of a magnesium-treated cast iron (C 3·5–3·7%, Si 2·2–2·5%) partly coiled in a sand mould and then quenched in water has been studied and compared with that of iron with no magnesium. In the former, only the austenite keeps in contact with the melt while the graphite grows in the nodular shape within the austenite. In the latter, both solid phases (austenite and carbon) remain in contact with the melt during decomposition and the graphite is lamellar. It is not the carbon diffusion process which determines the shape and rate of growth of the graphite, but the process of removal of iron atoms from the graphite crystallization front which ensures the widening of the voids in the austenite occupied by the graphite.—R. A. R.

Some Effects of Deoxidizing Additions on Foundry Malleable Irons. R. W. Heine. (American Foundrymen's Society, May, 1950, Preprint No. 50-11). From experiments on white cast iron melted under laboratory conditions and similar irons melted under foundry conditions, the author concludes that the effects of deoxidizing agents depend on the amount of residual oxygen in the melt at the time of the addition. The amount of aluminium used to deoxidize the irons reported was found to affect the size, distribution, and type of non-metallic inclusion present in the as-cast condition. From the examination of irons melted in various foundries, three basic types of inclusion were observed metallographically. Type I were random sulphides (large) and silicates, and they occurred in irons where no deoxidizing treatment was applied. Type II were found to develop when the metal was virtually deoxidized and are said to be eutectic sulphides, occurring in chains and galaxies. Silicates appeared to be absent when these inclusions were present. The amount of aluminium required for deoxidation and the production of type II inclusions was found to vary with the oxygen in the melt. Such inclusions were produced with aluminium additions ranging from 0·02 to 0·12% in different heats at different foundries. Deoxidation also affects graphitization, involving an initial decrease in the number of nodules followed by an increase as the aluminium content increases, providing the initial oxygen content is sufficiently high. The effects of titanium metal as a deoxidizer were similar to those of aluminium, though milder. Additions of aluminium and titanium, sufficient to produce virtually complete deoxidation and an alloying of the element, caused a new phase to appear at the grain boundaries of fully malleablized irons. This phase was considered to be a complex carbide.—E. J. D. S.

Blackheart Malleable Iron Foundry. (Engineer, 1950, vol. 189, June 23, pp. 736–737). This article describes the products and main foundry of Hale and Hale (Tipton), Ltd. Improved methods make it possible to produce castings with consistently high mechanical properties in weights ranging from a few ounces up to 120 lb. A description is given of the annealing process which converts the hard and brittle white iron into blackheart malleable iron. A description is also given of the extensive main foundry buildings which house a battery of pulverized-fuel-fired open-hearth melting furnaces of 17 to 25 tons capacity. Details are given of the tests taken during melts, of mould preparation and pattern shops, and of the methods taken to ensure a uniformly high standard production.—M. D. J. B.

Furnace Atmosphere for Malleable Annealing. W. D. McMillan. (American Foundrymen's Society, May 1950, Preprint No. 50-8). Since the presence of some air is almost unavoidable in commercial malleable annealing processes, the ratios of H_2/H_2O and CO/CO_2 in the atmosphere surrounding the iron affect the properties and structure of the final product. The following reversible reactions are discussed: (1) $Fe + H_2O \rightleftharpoons FeO + H_2$; (2) $Fe + CO_2 \rightleftharpoons FeO + CO$; (3) $CO + H_2O \rightleftharpoons CO_2 + H_2$; (4) $Fe_3C + CO_2 \rightleftharpoons 3Fe + 2CO$; (5) $CO_2 + C \rightleftharpoons CO$; (6) $2H_2 + Fe_3C \rightleftharpoons 3Fe + CH_4$; (7) $CH_4 \rightleftharpoons C + 2H_2$; (8) $Fe_3O_4 + 4Fe_3C \rightleftharpoons 15Fe + 4CO$. Graphs are presented to show the values of the equilibrium constants

$$K = \frac{(CO_2)\,(H_2)}{(CO)\,(H_2O)} \quad \text{and} \quad K = \frac{(CO)_2}{CO_2},$$

and the variation of CO_2/CO with Fe/FeO, at different temperatures. To determine the extent to which a low carbon monoxide atmosphere (7–8% CO, 4–5% H_2, trace CO_2, balance N_2) will carburize or decarburize, and the effect of surface on the annealing process, machined rolled steel bars, machined iron bars, and as-cast iron bars were subjected to an annealing cycle consisting of about 26 hr. at 1700° F. and 38 hr. between 1500° and 1300° F. All bars showed decarburization, but the as-cast specimens had a carbon content 0·3 to 0·8% lower than that of machined iron specimens at the corresponding depth of sampling.—E. J. D. S.

Steel Quality as Related to Test Bar Fractures. H. H. Johnson and G. A. Fisher. (American Foundrymen's Society, May, 1950, Preprint No. 50-41). Test-bar fractures can be grouped into two main classes: Cupped and non-cupped fractures. The first includes not only those that form a perfect cup and cone, but also fractures where each half of the test bar exhibits a portion of the cup and of the cone. The second class includes the irregular, angular, and flat types of fracture. Test results representing about 400 heats of steel were used to plot frequency diagrams which indicate that yield and ultimate strength distributions are similar for both types of fracture, but that the level of ductility, as measured by elongation and reduction of area, is markedly less for non-cupped bars. By statistical treatment of the results curves are given relating elongation and tensile strength, and ultimate tensile strength and reduction of area, for non-cupped and cupped fractures. The results for the latter were significantly superior to those for non-cupped fractures. The frequency of occurrence of non-cupped fractures and two general causes have been studied, one of which is related to the effect of gases in the steel, principally hydrogen.—E. J. D. S.

Nature of Mold Cavity Gases. C. Locke and R. L. Ashbrook. (American Foundrymen's Society, May, 1950, Preprint No. 50-10). Gas pressures formed in a mould cavity during the pouring of steel were investigated. Pressures were found to increase directly with increase in pouring rate, and showed a hyperbolic increase as permeability decreased. Pressure values were low and would be expected to be even lower under

comparable practical conditions. This is considered to be in agreement with the conclusions of Adams who showed that small moulds could be poured satisfactorily without venting. Permeability of a mould subject only to radiant heat during casting was found to be approximately the same as the permeability of the same mould tested at room temperature. Effects of mould compositions on mould gas analyses were also studied. E. J. D. S.

A Study of Factors Affecting Molding Sand Density, Shrinkage, Expansion, and Workability. R. P. Schauss, R. F. Baley, and E. E. Woodliff. (American Foundrymen's Society, May, 1950, Preprint No. 50-12). Sands bonded with various common clays were studied in order to determine the effects of sand properties on mouldability and casting quality. The results showed rammed density of moulding sand to be affected by the type and amount of clay bond. Sands were also tested after constant density ramming, which permitted the measurement of the energy of ramming for different sands and binders. Free and confined sand expansion tests were conducted, the latter method proving the most satisfactory for measuring the expansion of sands. The dilatometers are described.—E. J. D. S.

An Investigation of Metal Penetration in Steel Sand Cores. S. L. Gertsman and A. E. Murton. (American Foundrymen's Society, May, 1950, Preprint No. 50-13). Experiments were conducted to determine the effect of ferrostatic pressure on cores of different types and grades of sand. Gassy metal, core temperature, and ferrostatic pressure were found to promote metal penetration, although the latter cause was the most significant. Cores of 100% silica flour resisted penetration under the highest ferrostatic pressure, although a normal silica flour wash was not effective in reducing penetration. With a medium head of metal (15 in.) a washed wood-flour core helped to prevent penetration. No significant difference was observed between the penetration for sands of wide and narrow size distributions when the average size was the same. No significant benefit was obtained by increasing the ramming from 3 to 50 blows.—E. J. D. S.

Flowability of Molding Sands. W. H. Moore. (American Foundrymen's Society, May, 1950, Preprint No. 50-46). Past attempts to define and determine flowability are reviewed. Strength and permeability of a sand mould are considered to be the important factors which can be expressed in terms of 'ventability' and 'bondability' respectively. The average values for these properties are given as the flowability, which determines the latent ability of a sand to give uniform strength and permeability over the complete mould surface. The nature, grading, and moisture content of various sands are considered in their bearing on flowability, together with the effects of different methods of ramming.—E. J. D. S.

The "Abreuvage" Defect. (Foundry Trade Journal, 1950, vol. 89, Aug. 24, pp. 215–216). 'Abreuvage' is defined as penetration, by metal, into the interstices of sand grains by capillary action; it can be due to either physical or mechanical causes. Physical causes include fusibility of sand grains and capillarity; mechanical causes, the existence of accidental voids in the rammed sand, and the formation of cracks in the mould surface. A core scab also refers to an intimate mixture of metal and sand, but is due to different causes, including the use of a bonding agent having a low temperature of breakdown, the inclusion of too high a proportion of organic matter in the sand, or the distortion of the mass of the core by pressure effects developed when the core is surrounded by molten metal. A specific case is then briefly examined, the conclusions made being that a sand of too large a grain size had been used, and a better quality of dressing should have been employed.—J. E. W.

Foundry Facing Sand. J. Happich. (Fonderie, 1950, Apr., p. 2025). Foundry blacking is used to improve the finish of castings. The essential properties of a good facing are: (*a*) Minimum quantity of volatile matter: 30%; and (*b*) maximum ash content: 10%. The addition of facing sand considerably modifies the properties of foundry sand. The permeability is decreased whilst the cohesion is increased. A natural foundry sand, having a clay content of 12% and an A.F.A. (American Foundrymen's Association) fineness of 65 had the following properties: A.F.A. permeability of 100 and a compression strength of 1100 g./sq. cm. An addition of 4% of facing sand modified these properties as follows: A.F.A. permeability 80; compression strength 1200 g./sq. cm. Similar modifications were obtained by adding facing sand to a siliceous synthetic foundry sand. Optimum addition of blacking to foundry sand is 3 to 4%. Further addition of facing sand would lower the permeability. Bad finish on castings is often due to bad quality blacking or an insufficient content of volatile matter. R. S.

Pattern Materials and Production in Precision Investment Casting. E. I. Valyi. (American Foundrymen's Society, May, 1950, Preprint No. 50-33). Pattern materials for precision investment casting, including the use of metal patterns, are reviewed. Methods of modifying wax compositions are given. Development of pattern plastics is described and data are presented on comparative physical characteristics of pattern waxes and plastics.—E. J. D. S.

Foundry Patterns in Improved Plaster. P. Nicolas and J. Happich. (Fonderie, 1950, Nov., pp. 2237–2244). Wooden patterns cannot be used more than about 400 times and considerable time and expense are required to produce them. Metal patterns take time to make and are not cheap. Plaster patterns can be made quickly and cheaply but are very brittle. Magnesium cements and sand cements also have certain disadvantages. The addition of synthetic hardening resins to plaster opens up a wide field of possibilities. An account is given of laboratory tests on these mixtures, including tests for setting times, bend tests, tensile tests, hardness, and impact tests. Mixture compositions are presented. Although not offering an ideal solution to the problem of pattern-making, the technique of improved plaster patterns offers a vast field of application in the medium-capacity foundry. Precision, rapid production, and cheapness are characteristic of this type of pattern.—R. S.

Thermogenic Mixtures. (Mineração e Metalurgia, 1950, vol. 15, May–June, p. 11). [In Portuguese]. 'Thermogenic' mixtures are used in cores to give uniform temperature distribution and directional solidification. The heat of the molten metal initiates the exothermic reaction of the mixture, superheating the metal in contact with the mould and promoting uniform solidification. Thermogenic mixtures consist of: (*a*) A refractory element siliceous or aluminous; (*b*) an agglomerating element, mineral or organic; (*c*) granulated aluminium; and (*d*) oxidizing elements.—R. S.

Running Iron Castings—Use of Pencil Gates in a Ring Runner. P. Rigaut. (Fonderie: Foundry Trade Journal, 1950, vol. 89, Sept. 21, pp. 283–284). A method of running cylindrical castings, such as cylinder castings is described. A ring runner carrying evenly spaced pencil runners is used, the size of the different sectional areas being such that the whole can be constantly choked. To prevent impingement of the metal stream on the mould walls or on the core, care should be taken to ensure that the mould stands vertically. Suitable risers are employed to allow an easy escape of the mould gases. Advantages inherent in this method of running are that favourable feeding conditions are created, and corrosion on mould walls is eliminated.—J. E. W.

Marking Moulds at the Joints by Means of Steady-Pins. P. Rigaut. (Fonderie, 1950, Apr., pp. 2026–2027). Some methods, successfully used in green sand and baked mould casting practice, for marking the exact location of the cope on the foundry floor are briefly noted. Marking methods include the use of machined steady-pins placed in the flask to receive the rings fitted in the cope; hand-cut pins placed in the packing of the mould, and metallic pins.—R. S.

Feed Hoppers for Moulding Machines. P. Rigaut. (Fonderie, 1950, Mar., pp. 1987–1992). Moulding machine hoppers should be designed not too high and should possess a wide base aperture. Internal walls should be smooth and their slope should be suitable for the grade of sand used. Sharp internal angles should be rounded off. When small frames are filled, sand flow to the interior of the moulding box should be facilitated by means of a spout. Some current designs of feed hoppers are illustrated.—R. S.

Moisture Recovery in Cores. P. Nicolas. (Fonderie, 1950, Jan., pp. 1908–1913). A method of determining the increase of moisture in cores during storage is described. Increase in weight, due to moisture recovery, is of the order of only 10 mg./cu. m. The author's method is, therefore, based on a measure of the loss in resistance due to moisture recovery. An apparatus is described whereby a number of bend or tensile specimens are tested, on the one hand, immediately after baking and cooling in a drier in which the samples are

enclosed on leaving the stove; on the other hand, after 24 hr. in a 35% humid atmosphere. Resistances are determined before and after moisture recovery. The factors influencing the quality of agglomerated sand cores include the nature of the bonding, conditions of baking, and temperature and duration of stoving. The effects of these factors are illustrated by practical examples.—R. S.

Air-Setting Core Paste. (Foundry Trade Journal, 1950, vol. 89, Aug. 17, pp. 173–174). The production of a cheap air-setting core paste is described. Experiment showed that the most satisfactory composition consisted of 57% proprietary brand of clay, mixed to a smooth paste with 43% commercial sodium silicate. The shear strength of this clay, developed after 24-hr. air drying was 63·2 lb./sq. in., and the paste has been satisfactorily used in jointing half cores up to 1½ cwt. in weight. A disadvantage is that in cold weather the drying time is lengthened, but this may be overcome by storage at 60° F., or if this is impossible, by spraying the paste with a dilute solution of phosphoric acid.—J. E. W.

Moulding a Loco Cylinder. (Australian Foundry Trade Journal, 1950, vol. 1, May. pp. 14–16). After a brief history of the Morts' Dock and Engineering Co. Works, the method of making a locomotive cylinder is detailed. A solid pattern split in the centre to which are attached the loose pieces, bosses, flanges, coreprints, etc., is used and moulded up. The mould is given a heavy coating of a refractory paint, and dried. Cores are made in a sharp sand, bonded with a proprietary binder and bentonite. An iron former is employed, and a sand depth of 3 in. is used, the centre being filled with coke or ashes. After baking at 180–200° C. and blacking, the cores are bolted together. A feature in the use of this sand is the complete elimination of wax-vents, sprigs, nails, and other reinforcements used in the ordinary process of core making.—J. E. W.

Manufacture of Water-Tight Iron Castings. P. Rigaut. (Fonderie, 1950, July, pp. 2132–2134). A method is described for direct-pouring cylindrical shapes by means of a circular 'shower-bath' or collar device, often referred to as 'pencil casting.' The gates are distributed on the circumference of a collar so that they are slightly nearer to the core than to the internal surface of the mould. The advantages of this method over up-hill casting are: Avoidance of hot spots; a uniform temperature gradient; efficient feed; elimination of risk of mould erosion; and uniformity of distribution of metal over the entire section.—R. S.

Casting Francis Turbine Rotors in a Single Piece for an Electric Power Station. (Fonderie, 1949, Dec., pp. 1869–1872). The casting of two Francis turbine rotors in semi-mild steel for the Chastang (Dordogne) electric power station, is described. The wheels were 4·525 m. in dia. and weighed 42 tons finished. Details are given of the patterns, choice of sand, casting operations, tolerances, feeder head arrangements, and design of mould and cores.—R. S.

Regulating the Operation of Foundry Stoves. G. Ulmer. (Fonderie, 1950, Feb., pp. 1954–1956). The influence of various factors on the drying of moulds and cores, including condition of the hearth, the secondary air, and distribution of hot gases, is studied. Pyrometric checking of temperature is described. The control of hot gas distribution by judicious spacing of tiles in the furnace is illustrated. The calculation of heat balances for checking stove operation is explained.
R. S.

Metal Parts with High Accuracy and Finish Produced by New Casting Process. B. N. Ames, S. B. Donner, and N. A. Kahn. (Materials and Methods, 1950, vol. 32, Aug., pp. 43–46). The Croning, or 'C' process, developed in Germany, is now being exhaustively investigated at the New York Naval Shipyard. The process utilizes moulds made of a mixture of silica sand and finely powdered phenolformaldehyde resins. This mixture is applied to a hot metal pattern, and the whole baked at 600° F., after which the mould (a thin, even, insoluble shell of good strength) is stripped from the pattern. Trials have been made with aluminium, gun metal, bronze, grey iron, and medium carbon and stainless steels. Among the advantages claimed may be mentioned: (1) Cleaning of the casting is reduced or even eliminated, (2) machining is reduced, (3) thin sections down to 0·010 in. can be cast, (4) casting fidelity and finish are remarkably good. The exploratory casting of an impeller disc with thin blades is described, and the present work, which is being carried out on the suitability of different resin bonding agents, is briefly referred to.—P. M. C.

Precision Investment Castings Replace Parts Produced by Other Methods. R. L. Wood and D. V. Ludwig. (Materials and Methods, 1950, vol. 32, Sept., pp. 49–53). Precision castings of many ferrous and non-ferrous alloys can frequently replace components built up from several parts. By referring to nine typical parts, all of which are illustrated, the authors show how the casting technique greatly reduces production costs, eliminates the waste of metal, allows the selection of the most suitable alloy, and reduces finish-machining.
P. M. C.

'Soro' Process for the Casting of Bars. R. Genders. (Foundry Trade Journal, 1950, vol. 89, Sept. 28, pp. 305–312). The 'Soro' process employs the centrifugal principle as a means of converting liquid metal directly to the semi-finished condition in the form of bars suitable for machining in automatics or for cutting into forging billets. The method is producing between 1000 and 3000 tons of bars a year in two works. The bar is cast in the form of a hoop, and the section may be of any regular shape; the process is applicable to materials which are otherwise difficult to roll or extrude into bar form. The section is designed to leave at the centre a sink head, which also provides a reservoir for dross or slag which is centrifuged out of the metal. After casting, the shrink head is removed, and the bar is cut and straightened, preparatory to cutting into billets, forging, or upsetting. Solidification in this process is directional, which ensures soundness, and the 'drag' of the molten metal prevents the formation of zones of columnar crystals. There is also no segregation in the bar and few non-metallic inclusions. The structure is entirely equi-axed so that forging is possible in all directions to an equal extent and with equal effect. The capacity for deformation is very high, and the value of uniformity and absence of fibre is reflected particularly in the upsetting and piercing of billets to forge hollow shapes suitable for subsequent cold drawing. Tests made, comparing 'Soro' brass bars after several stages of cold drawing with wrought bars drawn to the same reduction, gave identical proof stress and tensile figures. The longitudinal ductility was somewhat lower, but the transverse ductility, higher. The bars are also virtually free from the risk of 'season cracking' under ordinary circumstances. Experimental trials have been made with austenitic rust-resisting steels, including copper-bearing types.—J. E. W.

Castings for River and Coastal Craft. A. G. Thomson. (Foundry Trade Journal, 1950, vol. 89, Sept. 21, pp. 269–272). Victor Moyle and Company, Hampton Wick, specialize in the production of intricate and difficult non-ferrous and iron castings, mainly for marine purposes. Pneulec 'Royer' sand mixers prepare the sand for the iron foundry and the melting is conducted by a 3-ton/hr. capacity cupola. The core shop and fettling shop are briefly described, and the method of production planning described more fully.—J. E. W.

Bandsawing in Foundries. G. H. Sheppard. (American Foundrymen's Society, May, 1950, Preprint No. 50-58). For ferrous castings the temperature at the point of cutting is said to be 1600–2600° F., and casting materials having softening temperatures within this range may be friction sawed economically. From the point of view of low tool cost, operator fatigue, and production rate, the maximum work thickness is limited to 1 in. Cutting rates for ductile iron, grey iron, and chromium and nickel castings are: Up to ⅛ in. thickness, 80–150 sq. in./min.; ⅛ to ¼ in., 20–80; ¼ to ½ in., 10–20; ½ to ¾ in., 8–10; ¾ to 1 in., 6–8 sq. in./min. Saw speed is determined by the composition of the castings. The relation between finish, production, and saw life, and the conditions saw velocity, saw pitch, and feeding rate are discussed. Tool costs depend almost entirely on the sawing technique and not on the cost of the blade.—E. J. D. S.

Use of Portable Air Tools in Foundry Cleaning Rooms. A. G. Ringer. (American Foundrymen's Society, May, 1950, Preprint No. 50-52). It is claimed that iron and steel foundries can handle most chipping operations with a chipping hammer with a 2-in. nominal piston stroke. A hammer with a 3-in. stroke is preferable for removing gates and risers, and for malleable iron or non-ferrous castings one with a 1-in. stroke is said to be of general use. Standard chisel and shank dimensions are given. Pneumatic grinders and combinations

of wheel speed, composition, and size are discussed. Recommended hose arrangements are tabulated.—E. J. D. S.

Solidification and Structure of Cast Irons. A. Descy. (Fonderie, 1950, Mar., pp. 1973–1981). The author attempts to show that seemingly exceptional and abnormal facts relating to the cooling of cast iron are actually frequent and normal. Examples are: (1) In cast irons containing pearlite + ferrite, sometimes the proportion of ferrite increases away from the surface of the casting, sometimes it decreases. The latter case, though of frequent occurrence, is contrary to admitted ideas. (2) Rapid chilling of castings containing ferrite + pearlite often produces a ferrite 'edge.' This contradicts the general conception of the effect of cooling. The Maurer diagrams do not indicate that rapid cooling often produces cementite and also pure ferrite at the surface. (3) The fact that a ferrite structure often alternates with a cementite structure without the intermediate pearlite phase is contrary to the silicon–carbon diagram for cast irons. (4) Although a ferritic structure is obtained by slow cooling, it can also be achieved by rapid cooling, contrary to the usual conceptions. Thicker castings are cooled more slowly to increase the proportion of ferrite, but rapid cooling of the same casting still further increases the amount of ferrite. Although this appears manifestly absurd, it is a fact.

The effects of different rates of cooling and mould materials on the structures of silicon irons are illustrated by auxiliary diagrams designed to improve the interpretation of the Maurer diagrams for Fe–C–Si and Si–C cast irons. The relationships between transformation to ferrite and the form of graphite are examined.—R. S.

Inspection and Storage of Foundry Lifting Equipment. W. M. Halliday. (Foundry Trade Journal, 1950, vol. 88, Aug. 17, pp. 191–192). The basic features of a practical scheme of inspection and storage services, designed to ensure proper control of chains and lifting equipment are briefly outlined. Regular and systematic inspection, together with detailed recording of movements, treatment, storage, and repair activities, is considered essential.—J. E. W.

Material Transport in the Cleaning Room. N. L. Smith and R. J. Wolf. (American Foundrymen's Society, May, 1950, Preprint No. 50-56). Attention is drawn to different features of the layout of the foundry cleaning room which may be a means of impeding production, and the importance of an easy labour-saving and adequate system of transporting foundry products, particularly through the cleaning room, is emphasized. The selection, limitations, advantages, and disadvantages of conveyor systems, light cranes, monorails, and trucks are briefly discussed from the point of view of plant layout.—E. J. D. S.

Foundry Apprentice Training at Caterpillar Tractor Co. F. W. Shipley and B. L. Bevis. (American Foundrymen's Society, May, 1950, Preprint No. 50-55). The scheme outlined provides a thorough technical training for young men unable to take an extended course of training at a college.

E. J. D. S.

Ventilation Units at Beevor Iron Foundry. (Engineer, 1950, vol. 190, July 21, pp. 74–75). The heating and ventilating systems installed in the recently opened Beevor Iron Foundry of Ruston and Hornsby, Ltd., Lincoln, are described.

M. D. J. B.

Contribution to Recent Research on the Causes of Silicosis. E. Nevyjel. (Báňský Obsor, 1950, vol. 4, July, pp. 97–103). [In Czech]. The author draws attention to some reactions which might cause lung diseases due to breathing in dust, as for instance, the metamorphosis of hard mineral particles into sericite.—E. G.

Review of Literature on Dusts. J. J. Forbes, S. J. Davenport, and G. G. Morgis. (United States Bureau of Mines, 1950, Bulletin 478). This Bulletin is a revision of Bulletin 400 published in 1937 and contains 657 references. The physiological effects of breathing dusts are examined and the incidence of dust diseases in 18 countries and seven different industries, including founding and mining, is reported.

R. A. R.

HEATING FURNACES AND SOAKING PITS

Automatic Vertical-Slot Furnace. (Engineering, 1950, vol. 170, Sept. 1, pp. 198–199). A description is given of an automatic vertical-slot furnace developed by the Incandescent Heat Co., Ltd., Birmingham. The furnace is specially suitable for heat-treating bars, tubes, sections, and strip material. These are fed into the top of the furnace and are conveyed downwards by an automatic mechanism, through the upward-flowing hot gases, on to a live-roll conveyor discharging the bars, one by one, at a speed of 200–300/hr. The furnace is compact and economical in fuel and space for the type of material it is intended to handle. The standard model can deal with bars from $\frac{3}{8}$ to $\frac{7}{8}$ in., 13 ft. long, at rates of 180 and 60 bars/hr., respectively. The heavy model will take bars up to 20 ft. long and $2\frac{1}{2}$ in. dia. at a rate of 36 bars/hr.—M. D. J. B.

How to Evaluate Induction Heating for Forging, Forming. (Steel, 1950, vol. 127, July 24, pp. 58–60). This article points out that although induction heating is expensive the advantages derived more than offset the disadvantages, as is indicated by its increasing use. The advantages described are, high rate of energy input and hence a shorter heating time, multiple operation can provide an uninterrupted flow of work, scale is almost eliminated, and the heating unit is immediately available for use and can be turned off when not required.

A. M. F.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Modern Developments in Heat-Treatment Practice. R. E. Leyman. (Journal of the South African Institution of Engineers, 1950, vol. 48, Mar., pp. 208–229). This paper discusses in general terms developments in heat-treatment practice during recent years. In the first section improvements in heating methods and in furnace design, and the utilization of controlled atmospheres in furnaces are discussed. The fields of usefulness for salt and lead baths and high-frequency and internal resistance methods of heating are briefly dealt with. The second section discusses the holding period, with particular reference to uniformity of heating and temperature control. The third section deals with some features of the cooling operation. The various types of isothermal transformation diagram are discussed, and new heat-treatment procedures based on these diagrams are illustrated. The importance of the temperature range of the martensite transformation in relation to quench-cracking is emphasized, and the available means of reducing this tendency are mentioned.

H. R. M.

Industrial Electric Furnaces. P. F. Hancock. (Metal Treatment and Drop Forging, 1950, vol. 17, Summer Issue, pp. 65–72, 77). The author reviews the various electric furnaces available for heating billets for hot working, and for heat-treatment. Resistor and induction methods of heating are described, and open-bath, controlled-atmosphere batch, and continuous types of heat-treatment furnace are described and illustrated. Particular reference is made to the types of atmosphere available.—P. M. C.

Some Aspects of Automatic Control of Heat-treatment Furnaces. A. Linford. (Metal Treatment and Drop Forging, 1950, vol. 17, Spring Issue, pp. 53–62). The author describes the basic principles of automatic control techniques, as applied to temperature and kindred controllers used on heat-treatment furnaces. Two and multi-position electrical automatic control systems are briefly described, but the main purpose of the article is to review the modern development in pneumatic-automatic control technique. The 'proportional,' 'proportional-plus-integral,' and 'first derivative' forms of control are explained.—P. M. C.

Transformation Processes as a Cause of Cracking in Deeply Carburized Steel Articles. F. Brühl and H. J. Wiester. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, May–June, pp. 159–163). Stress cracks, which occur in deeply carburized steel articles on cooling or normalizing, have been shown by dilatometric and micrographic studies to be due to the fact that under the chosen cooling conditions the carburized surface layer transforms in the pearlite range, whereas the low-carbon core transforms in the intermediate or martensite range. The marked expansion of the core during transformation leads to high stresses which the completely transformed skin cannot take up because its deformability has been reduced by the high-carbon content and the low temperature. Amelioration can be achieved by a pearlitizing anneal, *i.e.*, a more or less lengthy interruption of the cooling in the temperature region of the pearlite range, until the case and core have completely transformed or by an accelerated cooling in

which the transformation of the case occurs after that of the core; the expansion resulting from the formation of martensite counteracts the stresses produced by the transformation of the core.—J. P.

Industrial Annealing and Heat-Treating of Steel Bar with Particular Reference to Scaling, Decarburization, Heating Rate and Temper Brittleness. W. Hülsbruch. (Stahl und Eisen, 1950, vol. 70, July 20, pp. 641–653). Industrial practice for annealing and heat-treating drawn steel bars is reviewed. Surface finish (roughness) plays an important part in the ease with which drawing can be carried out and the effect of pre-annealing on finish and the ways to obtain optimum results are described. If surface decarburization is to be avoided, the annealing must be carried out under scaling conditions; the methods by which a readily removable scale may be produced have been worked out. The problems of scaling and bright finishing during heat-treatment after drawing, and the effects of protective atmospheres and furnace construction thereon are dealt with. Decarburization under industrial conditions is discussed on the basis of the results of Schenck and Neumann, and examples are given of the readiness with which iron carbide decomposes in carbon-containing atmospheres. Further industrial results are employed to illustrate the influence of annealing after cold reduction on physical properties as a result of precipitation processes, crystal recovery, recrystallization, normalizing, and heating rates. Pearlite coagulation is markedly accelerated by cold deformation. Cold shortness is favoured by cold drawing and subsequent annealing. In general, heat-treatment before drawing followed by tempering is preferable to heat-treating after drawing. The dominating influence of heating rate during austenitizing on grain size is shown. Slow heating induces the formation of coarse grains. This is attributed to the fact that at and after the passing of the Ac_1 point, nuclei in favoured places begin to grow. Cold deformation increases markedly the tendency to form coarse grains at low heating rates. For austenitizing, rapid heating, short heating periods, smallest possible overheating, fine-grained initial structure, and small dimensions are desirable. Similarly, rapid heating, short times, highest possible temperatures, and rapid cooling are desirable for tempering. Temper brittleness is a complex matter and is influenced by all previous treatments. The drawing of steel bar favours embrittling influences, so that special care must be taken. Sorbitic structures appreciably lower the temperature necessary to remove cold work. Questions of furnace construction are briefly mentioned.—J. P.

How Cleveland Pneumatic Heat Treats Giant Forgings. (Steel, 1950, vol. 127, Aug. 14, pp. 102–105). This article gives a short description of a new plant, at the Cleveland Pneumatic Tool Company's works, for heat-treating very large aircraft landing-gear forgings. The principal unit is a pit-type hardening furnace with a working capacity of 48 in. dia. by 13 ft. deep. Other units include a stress-relieving furnace, a tempering furnace, an atmosphere generator, and a special cooling pit.—A. M. F.

Influence of Size and Shape of Parts or Test Specimens upon Case Depth and Case Composition in Case-Hardening and Metallic Impregnation of Steel. M. M. Zamyatnin. (Doklady Akademii Nauk S.S.S.R., 1949, vol. 68, No. 4, pp. 725–728). In this mathematical paper formulæ are developed for relating the carbon concentration, depth of penetration, and time when case-hardening specimens of different shape.—R. A. R.

Wear Resistance of Black-Heart Malleable Iron. G. Joly. (Fonderie, 1950, Feb., p. 1959). To transform the ferrite and graphite structure to pearlite and graphite, the castings are heated to a temperature above the Ac point (870–900° C.) and held about 45 min. This puts a portion of the annealing carbon into solution in the austenite. The castings are then cooled to room temperature, the mechanical properties depending on the rate of cooling. To obtain pearlite with 240 Brinell, the rate of cooling should be about 20° C./min. A cooling rate of about 300° C./min. gives 270 Brinell. Cyaniding and flame and high-frequency induction hardening are other methods of obtaining high superficial hardness.—R. S.

Surface Hardening of Pearlite Malleable Irons. S. H. Bush, W. P. Wood and F. B. Rote. (American Foundrymen's Society, May, 1950, Preprint No. 50-53). Nine malleable irons differing in composition, production practice, and microstructure were investigated for response to surface hardening by flame and induction methods. Within the limits investigated chemical composition showed no noticeable effect on the response to induction hardening, although an increase in the manganese content was accompanied by an increase in hardness and depth of effective case in irons of similar lamellar structure when flame-hardened. A microstructure consisting of a dense pattern of finely spheroidized cementite consistently yielded the highest hardness values at a case depth of 0·060 in. and a maximum depth at 50 Rockwell C, in induction-hardened specimens, and also proved consistently satisfactory in all the flame-hardening tests. The microstructure which proved to be the least satisfactory for both methods of hardening consisted mainly of a matrix of ferrite and coarsely spheroidized cementite.—E. J. D. S.

Flame Hardening Now Widely Used for Surface Hardening Steels and Irons. E. F. Green. (Materials and Methods, 1950, vol. 32, Aug., pp. 56–59). The author describes in general terms the advantages of flame-hardening for specific jobs, the materials which can be treated, quenching techniques, the need for stress-relieving, equipment, and fuels.—P. M. C.

Continuous Carburizing Adapted to Job Shop Lots. H. Chase. (Iron Age, 1950, vol. 166, Aug. 31, pp. 61–63). This paper describes a new automatic continuous gas-carburizing installation at the Jackson plant of the Clark Equipment Co. Two three-row, tray-pusher type, radiant tube surface combustion furnaces are being used to carburize up to three depths at the same time in the same furnace.—A. M. F.

Industrial High Frequency Heating. R. H. Barfield. (Journal of the Institution of Production Engineers, 1950, vol. 29, Apr., pp. 165–181). The theory and practice of induction heating are reviewed and a description given of an industrial apparatus for hardening and tempering small gear wheels. A short account of dielectric heating is also presented.—J. W. P.

Induction Heating. J. Vazquez White. (Anales de Mecanica y Electricidad, 1949, vol. 25, Nov.–Dec., pp. 355–362; 1950, vol. 26, Mar.–Apr., pp. 91–104). [In Spanish]. The principles of induction heating are briefly reviewed and a warning is given that induction hardening cannot always replace with advantage the normal methods of hardening. The advantages of induction hardening mentioned are: Uniformity of temperature; increased hardening effect; improved machinability; less heating time; and no subsequent dressing is necessary.—R. S.

High-Frequency Hardening of Cast Iron. (Technika a Život, 1950, Feb., p. 23). [In Czech]. The strength, fatigue limit, and wear resistance of high-frequency hardened specimens were investigated and compared with those of the same material hardened by other methods.—E. G.

Induction Hardening Arbor Used on Automatic Screw Machine. W. G. Patton. (Iron Age, 1950, vol. 166, Aug. 24, pp. 65–67). The Saginaw Steering Gear Division of General Motors have introduced a high-frequency internal hardening induction unit for one operation on an eight-spindle automatic screwing machine. This reduces considerably the time required to produce universal joint bearings and eliminates the steps of copper plating, carburizing, tempering, and grinding. A. M. F.

Induction Surface Hardening Expedites Production, Saves Manpower. (Steel, 1950, vol. 127, Aug. 28, pp. 77–78). The use of induction heating means that medium carbon steels can be surface hardened after machining, thus saving on the cost of alloy steels. A heating unit is readily adaptable for many different parts and continuous processing is possible; other operations such as hardening and brazing, and hardening and shrink-fitting can be carried out.—A. M. F.

Cylindrical Parts Induction Heated in Continuous High Speed Production. W. L. Corteggiano. (Steel, 1950, vol. 127, Aug. 21, pp. 94–95, 104). This article describes a new automatic machine made by Westinghouse Electric Corp. for heat-treating cylindrical parts. The machine can handle shafts from $\frac{3}{8}$ to 2 in. in dia. and from $1\frac{3}{4}$ to 18 in. long. It has an automatic feed and discharge and can thus fit into a continuous production line.—A. M. F.

Rapid Tempering by Induction Heating. J. F. Libsch and A. E. Powers. (Metal Progress, 1950, vol. 58, Aug., pp. 176–180). Results of tests show that low-alloy steels can be

tempered within a few seconds by induction heating. Curves of hardness against tempering time and temperature show that rapid induction-heating tempering is equivalent to normal furnace tempering for one hour at a lower temperature. Impact strength and stress relaxation for specimens from each process are similar.—E. T. L.

Nitriding the Martensitic Stainless Steels. H. E. Boyer. (Steel Processing, 1950, vol. 36, July, pp. 353–357; Aug., pp. 403–407, 421). Of the ferritic, austenitic, and martensitic types of stainless steel, the last named forms the weakest oxide film, and is therefore the easiest to surface-harden. Six different steels of this type containing from 0·13 to 1·52% C, and from 11·75 to 17·15% Cr, were quench hardened and tempered, to produce homogeneous structures suitable for nitriding. The hardnesses at this stage ranged from 31 to 57 Rockwell C. After surface grinding and normal ammonia nitriding treatment, the case hardnesses, measured by the Superficial Rockwell-15N. scale, ranged from 95 to 96·5 (nearly 2000 V.P.N.). Case depths were, however, less than those obtained on a normal low-alloy nitriding steel. All the cases showed maximum hardness for 0·002 to 0·003 in., but the hardness fell rather rapidly at greater depths. Microphotographs, showing the transition from case to core structure, are shown for all six steels. The corrosion resistance after nitriding, as assessed by the salt-spray test, is inferior to that in the annealed condition.—P. M. C.

The Influence of Construction and Power Input of Electrically Heated Annealing Furnaces on Through-Put and Uniformity of Mechanical Properties of Steel Bars. H. Müller. (Stahl und Eisen, 1950, vol. 70, July 20, pp. 654–658). Annealing was carried out in two furnaces, with and without air circulation, at different temperatures and with different methods of stacking and power input in order to determine the most suitable conditions for high through-put, low loading of the electric mains, as well as uniformity of the physical properties of the steel. The following results were obtained: Except at high temperatures, high power inputs are best avoided on account of the short periods during which the current is actually passing and the lack of uniformity of physical properties. There is no essential reduction of output when the power supply is reduced. Open stacking favours rapid through-heating; the reduction in furnace utilization is insignificant. The air-circulation furnace is superior to the radiation furnace in output and in reduced strain on the electrical mains.—J. P.

Stress Relief. T. M. Jasper and W. C. Stewart. (Metal Progress, 1950, vol. 58, July, pp. 79, 80, 112, 118). This is a summary of four processes used for relieving stresses, *i.e.*, peening, annealing, repeated stressing, and overstressing. Methods for testing for stress relief are considered and several references given. A table is given for seven different steels of the retained stresses after different degrees of anneal.—E. T. L.

Modern Heat Treating. III—Interrupted Quenching. W. Adam, jun., and L. B. Rosseau. (Metal Progress, 1950, vol. 57, June, pp. 765–768). This article outlines modern methods of austempering, martempering, cyclic annealing, and solution treatment for age-hardenable alloys. Interrupted quenching is explained by time-temperature-transformation diagrams, and applied to the use of electrically heated salt baths.—E. T. L.

FORGING, STAMPING, DRAWING, AND PRESSING

Material Handling in the Forging Industry. J. C. McComb. (Steel Processing, 1950, vol. 36, July, pp. 329–345). The author describes the forging equipment, plant layout, and handling methods employed in representative American forges. Four heavy forges, two light impression die forges, and eight pressworking and stamping shops are described. The uses of cranes, porter bars, rotating burden chains, and mechanical manipulating machines are outlined for the movement and handling of large ingots. In works producing small items, smooth production flow lines are based on mobile cranes, conveyors of the belt and monorail type, and movable storage bins which are moved about by the ever-present fork lift truck.—P. M. C.

Composite Forgings for Die Manufacture. (Mechanical World, 1950, vol. 128, July 28, pp. 75–78). Homogeneous dies, fabricated from mild-steel base pieces and tool-steel cutting edges, for use in the sheet-metal working industries, are described. Economies of more than 30% in die costs are claimed.—J. W. P.

Time Standards for Die Sinking. C. N. Harwood. (Steel Processing, 1950, vol. 36, Feb., pp. 71–75; Mar., pp. 130–134, 149; Apr., pp. 189–193, 199; May, pp. 244–249; June, pp. 288–294; July, pp. 348–350). These articles describe how time standards are deduced and applied to various die-shop problems, the aim being to enable the working time for any die-sinking operation to be predicted to within 5%. The production of a pair of dies, a trimmer or a punch, is a function of the amount of metal which has to be removed from the flat blocks, and of the complexity of the shape or profile. The author, by referring to several detailed examples, shows how the volume, profile, number of surfaces, and number of depths, etc., can be connected by an empirical formula for any type of operation. This is done by studying the times required to carry out say a dozen typical jobs, and then juggling with the above-mentioned variables until a satisfactory empirical time formula is evolved. These so-called time standards only apply of course to the shop in which they are determined.—R. M. C.

The Manufacture of Detachable Bits. J. Dolan. (Journal of the South African Institution of Engineers, 1950, vol. 48, Feb., pp. 163–205). After outlining the stages in the development of the 'P and M' detachable bit, which has a taper socket fitting the end of the drill stem, for drilling in gold mines, the plant and methods used for its manufacture in the mines of the Central Mining-Rand Mines Group are described. Bits are forged at 1050° C. in 200-ton presses, using slugs cut from 0·75% carbon steel bar, the usual size being a 1⅜-in. bit made from 1-in. bar. The central water hole is then punched out and the cruciform bit edge-ground. The bits are heated to 720° C. and the edges quenched on a travelling belt with ¼ in. depth of water. Worn bits are reforged and reground so long as they have sufficient head thickness. With an annual output of 1·8 million new and 4 million reconditioned bits the total cost is about 2·6 pence for new bits or 1·1 pence for reconditioning. Operating data with these bits at various mines are given.—H. R. M.

The Forging of Steel Anchor Chain. C. D. Linnenbank. (Steel Processing, 1950, vol. 36, Aug., pp. 392–397). The author describes the production of fully forged, weldless 'Di-Lok' chain. This unique, patented process, consists of drop forging the metal of an upset pierced half link, into the serrations of a previously forged and heat-treated 'male' link. This type of chain has been adopted as its standard by the U.S. Navy.—P. M. C.

American Drop Forging Practice. H. A. Wallace. (Metal Treatment and Drop Forging, 1950, vol. 17, Summer Issue, pp. 111–114). This article is a very brief summary of the more important points from the Report of the Drop Forgers and Stampers Productivity Team, of which the author was the team leader. The Americans do achieve higher productivity than the British drop forger, and the author considers this fact in relation to the following: High rate of machine utilization, mechanical handling, ample labour, specialization among firms, overhaul of machinery before breakdown occurs, cold clipping of small forgings, and excellent plant layouts. P. M. C.

Conversion of Existing Presses to the Direct Hydraulic System. F. H. Towler. (Mechanical World, 1950, vol. 128, July 7, pp. 1–5; July 14, pp. 33–35, 44, 45; Engineer, 1950, vol. 189, June 30, pp. 758–761; Machinery, 1950, vol. 77, July 6, pp. 3–11). The author considers the modern trend in which many central hydraulic accumulator plants are being converted to the direct hydraulic system; the hydraulic presses are powered by individual high-speed pumps using oil instead of water as the hydraulic medium. The reasons for conversion and the advantages of the direct hydraulic system are discussed in detail and the engineering involved in converting existing presses to the new system is described. The speed of operation, power of electric motors, construction of the presses, hydraulic packings, and reconditioning of existing rams are considered as well as oil supply, oil viscosity, and type of pump.—M. D. J. B.

Forging Presses. M. Monsalve Flores. (Anales de Mecanica y Electricidad, 1949, vol. 25, Nov.–Dec., pp. 347–354; 1950, vol. 26, Jan.–Feb., pp. 35–45; Mar.–Apr., pp. 81–90). [In Spanish]. The power systems employed for presses of different capacity are described.—R. A. R.

Compression-Formed Steel Tubing Offers Close Tolerances and High Strength Properties. L. A. Karg. (Materials and

Methods, 1950, vol. 32, Aug., pp. 52–55). The author describes the 'Rockrite' process by which tubing is produced by using semi-circular grooved dies that rock back and forth over the tube. This compresses the metal (cold) against a mandrel which controls the inside diameter. Tubes ranging from $\frac{7}{8}$ in. up to 6 in. can be formed in almost any kind of metal, and a wide variety of internal shapes, other than round, can be produced by suitable mandrels. Tolerances, surface finish, and mechanical properties are all discussed and claimed to be improved by this process.—P. M. C.

Some Problems Connected with the Pressing of Motor-Car Body Panels. G. A. Knight. (Newport and District Metallurgical Society: Sheet Metal Industries, 1950, vol. 27, Apr., pp. 325–334). The large double-acting crank press is the tool used for this class of work, the steel sheet usually being of the open-hearth rimming variety, containing 0·04 to 0·08% C, 0·25 to 0·30% Mn, and very little silicon. In the annealed condition this class of material is, unfortunately, subject to 'stretcher-strain' marking—a condition usually removed by giving the annealed sheet a 'skin-pass,' (about 1% reduction). If, however, the pressing operation is not carried out within a few days of 'skin-passing,' the material 'strain-ages' and once more becomes subject to the formation of 'stretcher-strains.' The author very briefly outlines Cottrell's dislocation theory of this ageing phenomenon, and refers to the non-ageing steels containing aluminium, titanium, or vanadium. Valuable information about cold-pressing properties can be obtained from simple tensile tests on 8-in. gauge length × $\frac{3}{4}$-in. wide specimens. The yield/ultimate tensile strength ratio, and the uniform elongation (*i.e.*, omitting the 'neck'), are two informative figures. For successful press work the former should be in the range 60–65%, and the latter not less than 22%, both figures being for open-hearth rimming-type steel. The effect of grain size and carbide distribution is also briefly discussed.—P. M. C.

The Production of Light Deep-Drawn Parts on Multi-Stage Presses. J. H. Hayes. (Sheet Metal Industries, 1950, vol. 27, May, pp. 419–421). In a multi-stage or gang press, up to ten separate rams are operated by one driving shaft. A complete deep-drawing schedule can therefore be carried out rapidly on one machine. The transfer of the article from one station to the next is fully automatic, so that blanks are fed in at one end of the battery of rams, and finished parts are ejected at the other. British and Continental makes are usually operated by the crank or eccentric shaft principle, and will accommodate blanks up to approximately $3\frac{1}{4}$ in. dia. and up to 0·050 in. thick (in brass). Speeds of up to 60 finished parts/min. can be attained. American makes usually employ cam-operated rams, which allow higher production rates. Cups up to 3 in. deep and 2 in. dia. in $\frac{1}{8}$ in. sheet have been satisfactorily produced. On small machines, speeds of 150 parts/min. are not uncommon.—P. M. C.

Cold Pressing of Dies and Mould Parts. (Technická Práce, 1950, Feb., pp. 24–27). [In Czech]. The results of experiments in the cold pressing with dies and the individual stages of production by this method are described, namely the preparation and annealing of the initial material, fine-grinding of the surface, pressing, annealing to eliminate internal stresses, machining, hardening, and finish-machining after hardening.—E. G.

Electromagnetic Starting of Presses. R. Havel and S. Z. Brno. (Kovodělny Průmysl, 1950, June, pp. 111–112). [In Czech]. An electromagnetic starting device for presses is described which is designed to prevent any possibility of accidents. To start the machine the operator must pull two levers, one with each hand, thus ensuring that his hands are outside the danger zone.—E. G.

Metal Working Machinery. G. Oehler. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, July, pp. 475–481). This is a description of machinery shown at the 1950 Hannover Exhibition, the bulk of which was of German manufacture. The author notes the absence of heavy presses and of some semi-automatic sheet-working presses of the vertical spindle type recently marketed in the U.S.A. The mechanical presses were suitable for new or improved safety devices. Other machines, such as shears, straighteners, wire-drawing and fabricating machines, pneumatic hammers, and small forging machines, were of conventional design.—J. G. W.

The Marform Process of Deep Drawing and Forming. R. B. Schulze. (Machinery, 1950, vol. 76, June 15, pp. 851–856). **Deep and Tapered Stampings without Wrinkles.** R. B. Schulze. (Metal Progress, 1950, vol. 57, June, pp. 769–772). The author considers the Guerin process for stamping small parts, and then the improved Marform process. In the latter, a steel pressure plate prevents rubber pads pressed on to the work from moving sideways, and also holds the parts of the work extending over the edge of the form block below it. In this way complicated cup-shaped pressings are obtained without wrinkles, and there is no need to have expensive accurately matched dies.—E. T. L.

The Use of Automatic Slide Feeds on Power Presses. J. L. Williams. (Sheet and Strip Metal Users' Technical Association: Sheet Metal Industries, 1950, vol. 27, June, pp. 517–522). The author describes various types of automatic feed used in connection with handling sheet and strip metal. There are two classes of feed mechanism: (*a*) Auxiliary equipment which can be fitted to any press already in service, and (*b*) that which is made as an integral part of the press. Of the several kinds of mechanism described and illustrated, the double-roll feed appears to be the most popular. Several typical installations are described and illustrated.—P. M. C.

Flow-Pressing of Steel. H. Hauttmann. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 235–242). The characteristic features of the Neumeyer flow-pressing method of cold-shaping steel are described. The method produces hollow, generally cylindrical, forms such as tubes, cups, etc., by a drawing process in which the plug controlling the internal dimensions also serves to force the steel through the die. The most efficient lubricants have been found to be electrodeposited zinc, phosphate, and electrodeposited copper coatings, treated with grease. Although the phosphate coatings are not quite as efficient as zinc, they have the advantage that they can be very readily removed by pickling. Small entrant die angles require the lowest pressing load and give the most favourable flow of metal but produce the largest stress in the die. Industrial tools use an angle of 125–130° as a compromise. The pressing load and Vickers hardness increased with all steels tested as the die angle was increased, and the impact strength decreased markedly. Tests on the influence of degree of reduction on the required pressing load under standard conditions showed that log reduction was a linear function of log load, steels with up to 0·12% C, between 0·12% and 0·27% C, and between 0·45% and 0·50% C, giving three separate straight lines. Results of impact tests showed a characteristic difference between steels containing and those free from aluminium. A works test to assess the suitability of steels for the process and a ring method for measuring impact strength of the finished tubes are described. J. P.

Cold Finished Bars. H. M. Smith. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 201–207). The production of cold-finished steel bars by the cold-drawing and cold-rolling processes and by turning and polishing, is briefly described, and the improvements in mechanical properties, machinability, and surface quality, are indicated. Reference is also made to the cold drawing of special sections.—G. F.

Drawbench Innovations Speed Line Production. (Steel, 1950, vol. 127, July 31, pp. 65–66). The Loma Machine Mfg. Co. of New York has developed a drawbench for processing steel, brass, copper, and other non-ferrous rods of round, hexagon, square, or rectangular section direct from coiled stock at 250 ft./min. Stock in the unit is pulled through the die at uniform speed and the gripping tool never requires changing regardless of size and shape of stock. The gripping tool is made up of two chains opposite to one another and the clamping pressure between them is kept automatically directly proportional to the actual pulling force.—A. M. F.

Steel Wire. F. Eickleman. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 245–251). A brief outline is given of the manufacture, terminology, and classification of steel wire and of the methods of heat-treatment employed to impart or control its physical properties.—G. F.

Procedures and Apparatus for Measuring Drawing-Die Profiles. W. Lueg. (Stahl und Eisen, 1950, vol. 70, July 20, pp. 633–640). The procedures and apparatus available for measuring die profiles are reviewed. Modern equipment, which employs optical or mechanical probing methods for

producing an enlarged image of the profile, is discussed at length, the B.I.S.R.A. and Askania instruments being the only commercial ones illustrated. Optical procedures for measuring die angle and their development for industrial use are described.—J. P.

ROLLING-MILL PRACTICE

Modern Electrical Equipment for the Reversing Blooming and Slabbing Mill. W. E. Miller. (Blast Furnace and Steel Plant, 1950, vol. 38, Feb., pp. 207–220, 248; Mar., pp. 311–340, 380). In Part I of this article the main drive is considered. A general method is described for selecting the reversing motors for blooming and slabbing mills which is based fundamentally on a comparison of the work to be done in the mill under consideration and the power required to do similar work on existing mills of the same type. The selection of electrical equipment, motor generator set, and control systems is discussed. Part II of the article deals with the auxiliaries. The rôle of the amplidyne control system for auxiliary machinery is described.—J. P. S.

Electrical Developments in 1949. H. W. Poole. (Blast Furnace and Steel Plant, 1950, vol. 38, Jan., pp. 77–80). The author discusses the value of the 'amplistat' which he says represents the latest advance in amplifiers for industrial regulating circuits. He describes the improvements, due largely to better control, in the rolling mills. A 100-kV. X-ray gauge now makes it possible to measure the thickness of strip as it emerges from the finishing stand of a continuous hot strip mill.—J. P. S.

Electronic Controls as Used in Finishing Steel. R. W. Barnitz. (American Iron and Steel Institute: Blast Furnace and Steel Plant, 1950, vol. 38, June, pp. 649–655). The varied uses in the industry for a photo-electric tube are outlined. Details are given of its application as a side register control on a winding reel of an electrolytic tinning line. The operation and electronics of the welder for welding together coils before cold rolling are described. The rôle of X-ray equipment for measuring the thickness of hot and cold strip is discussed. A description of electronic control in the wire-drawing process is given.—J. P. S.

Speed Control for Plate-Mill Motors. (Engineering, 1950, vol. 170, July 28, p. 95). This article describes amplidyne control equipment designed by the British Thomson-Houston Co., Ltd., to replace the controllers of two large reversing plate-mill motors at the Redcar Works of Dorman, Long and Co., Ltd. Amplidynes are quick-response D.C. generators requiring only small field powers or changes of field for their excitation and output control. With this new control scheme, the 50-r.p.m. base speed of the smaller mill motor can be increased to the full speed of 100 r.p.m. in about 5 sec. Similar retardation can also be effected in the same time. The fundamental principles of amplidynes, their operation, and practical applications are briefly described.—M. D. J. B.

Electrical Equipment for Merchant Bar and Rod Mills. W. B. Snyder. (Blast Furnace and Steel Plant, 1950, vol. 38, Apr., pp. 427–437). The selection of motor sizes and speeds for the continuous mill is discussed. Excitation circuits are described and the functions of the control desk are given. The operation of the mill is outlined and rectifier power supply is discussed. Details are given of additional features which are incorporated in modern bar and rod mill equipment to meet special conditions resulting from the characteristics of direct-current motors under charging loads. The article ends with a discussion of auxiliaries.—J. P. S.

The Present and Future of Power Electronics in the Steel Industry. L. A. Umansky. (Blast Furnace and Steel Plant, 1950, vol. 38, June, pp. 656–661). Direct-current power and steel-mill rectifiers are discussed. The use of rectifiers for a 250-V. supply is compared favourably with the use of motor generators. The application of electronic frequency changers to enable two power systems of different frequency to be interconnected is described.—J. P. S.

A Theoretical Investigation of Roll Flattening. D. R. Bland. (Proceedings of the Institution of Mechanical Engineers, 1950, vol. 163, pp. 141–148). *See* Journ. I. and S.I., 1951, vol. 167, Jan., p. 93.

Relations between Roll-Force, Torque, and the Applied Tensions in Strip-Rolling. (Proceedings of the Institution of Mechanical Engineers, 1950, vol. 163, pp. 135–140). *See* Journ. I. and S.I., 1951, vol. 167, Jan., p. 93.

British Iron and Steel Works Plant and Practice (5). Hot Rolling Mills: Two-High Reversing Blooming and Structural Mills. W. W. Franklin. (Iron and Coal Trades Review, 1950, vol. 161, July 21, pp. 121–132, 134). The author describes the design and operation of primary rolling mills and of mills for the production of heavy sections. The main features of two-high reversing blooming mills are discussed in detail, together with auxiliary plant, and the design of structural mills is briefly considered.—G. F.

WELDING AND FLAME-CUTTING

Calculation and Design of Welded Double-Walled Vessels. J. Němec. (Svařování, 1950, vol. 10, Aug., pp. 98–106). [In Czech]. The author critically examines H. Gerbaux's paper on the design of welded doubled-walled pressure vessels. On the basis of theory and experimental investigation the present author concludes that although simple formulæ can be derived for calculation of some of the stresses, peak bending stresses, particularly in the case of sharp angles, at the side walls must be neglected. In many cases stresses due to differences in expansion have to be taken into consideration.

Welding or Casting? E. Piwowarsky. (Neue Giesserei, 1950, vol. 37, Feb. 9, p. 52). Data on relative cost (from L. F. Williams) and on the dimensions of some welded structures (from E. J. Charlton) are quoted to illustrate the relative merits of welding and casting techniques.—O. H. G.

Better Weldments through 'Tailored' Quality Control. O. T. Barnett. (Steel, 1950, vol. 126, May 22, pp. 80–82). The author gives an outline of the welding procedure, training of operators, and types of inspection required to maintain quality in welding.—A. M. F.

Oxyacetylene Welding of Sheet Steel. E. Henrion. (Pratique du Soudage, 1949, vol. 3, Oct., pp. 138–142). The author reviews the many advantages which may be derived by oxy-acetylene welding sheet steel. The extra mild nature of sheet makes this type of fusion welding particularly suitable since the low carbon content enables small neat runs to be laid with no splashes or blowholes. Other advantages are: The ductility of the welds, speed of welding, and economy, since the addition of weld metal is kept to an absolute minimum. The use of jigs is recommended. Even rudimentary jigs for comparatively simple work speed up and ensure a better standard of welding. A description is given of a number of welded vessels and tubes.—M. D. J. B.

Joining Large Sections of Low Alloy Steels by Gas Pressure Welding. A. I. Nussbaum. (Materials and Methods, 1950, vol. 31, Apr. pp. 60–62). This article describes the Uniweld process, used by the Menasco Manufacturing Co. (U.S.A.), for fabricating aircraft landing gears. Uniwelding is accomplished by butting together under pressure two machined faces of the parts to be joined, at the same time heating the area of the weld plane by oxy-acetylene flame until sufficient upsetting takes place. The process is being applied to chromium–molybdenum and nickel–chromium–molybdenum low-alloy steels with between 0·25 and 0·45% C, and to tubular components between 1 and 20 in. in outside dia. and minimum wall thickness of 0·125 in. All welds are subsequently heat-treated to regain a tensile strength of 180,000 to 200,000 lb./sq. in. Details of the welding equipment and procedure are described, pressures in the range 3000–10,000 lb./sq. in. and temperatures of 2400–2500° F. being used for this particular job.—P. M. C.

Salvage of Castings by Welding of Defects. B. E. Bellew. (American Foundrymen's Society, May, 1950, Preprint No. 50-60.) The equipment, materials, electrodes, and techniques for arc welding of mild steel, low-alloy steel, and stainless-steel castings are discussed on the basis of efficiency and adaptation to foundry requirements. Important factors in the economics of salvaging castings are stressed, particularly the accurate estimation of operating costs—which is acknowledged to be difficult—and the skilful selection of castings which can be economically salvaged. The welding of non-ferrous castings is also discussed, including the new processes for inert-gas-shielded arc welding.—E. J. D. S.

Recommended Practices for Salvaging Automotive Gray Iron Castings by Welding. (American Welding Society, 1950, D.83-50T). Information is given on the repair of cylinder blocks and other automobile castings by oxy-acetylene and shielded metal-arc welding with and without preheat, brazing, soft-soldering, metallizing, and the use of mechanical methods.—R. A. R.

XUM

Hardfacing Applications in the Steel Industry. J. J. Barry. (Welding Journal, 1950, vol. 29, Mar., pp. 198–203). The use of hard-facing in the steel industry is described. Excavating equipment can be welded with an electrode of low-alloy ferrous material (0·85% C, 5·0% Cr, 0·9% Mn, and 0·55% Si) or a nickel–manganese steel electrode, depending on the type of steel to be welded. The hard-facing of steel-mill equipment has proved to be highly economical.—U. E.

Hard Surfacing by Welding. A. V. Houston. (ESC News, 1950, vol. 4, No. 2, pp. 2–6). Three types of rod for depositing hard alloys by welding are described. One type consists of cobalt–chromium–tungsten alloys in three grades to give hardnesses of 720, 560, and 430 Vickers, respectively. The second type is really a mild-steel tube full of particles of tungsten carbide, and the third covers welding electrodes containing varying amounts of chromium, nickel, molybdenum or manganese. The first two types each cost about 20 times as much as the third. A few examples of their use on such items as lifting dogs for cold ingots, soaking-pit dog pins, and shear blades for hot billets and blooms are discussed and illustrated.—R. A. R.

Electric Weld Tube Mill Goes into Production at National Tube Co.'s McKeesport Works. (Iron and Steel Engineer, 1950, vol. 27, June, pp. 120–122). A brief description is given of a new tube mill with an annual capacity of 100,000 tons of electric welded steel pipe in sizes ranging from 26 to 36 in. The conversion of plates into tubes is accomplished in 16 new machines. Mechanical handling equipment is a feature of the new mill.—M. D. J. B.

Localized Heating. P. A. Furkert. (Industrial Heating, 1950, vol. 17, Aug., pp. 1334–1342). The author discusses various techniques for local heating and their application to particular production problems, including brazing and silver soldering, combined local and full heating, stress relief, aluminium brazing, and local low-temperature heating.

J. A. L.

On the Metallography of the Weld of Blackheart Malleable Cast Iron. S. Blažek. (Hutnické Listy, 1950, vol. 5, Sept., pp. 374–375). [In Czech]. The author investigated microscopically and by hardness measurements welds of blackheart malleable iron. He found that cracks in such welds are caused by diffusion of carbon from the iron of the part into the weld and the rapid cooling. This gives the weld a martensitic structure.—E. G.

Repair and Reclamation of Grey-Iron Castings by Welding and Allied Methods. (Institute of British Foundrymen, 1950, Paper No. 969: Foundry Trade Journal, 1950, vol. 89, Aug. 24, pp. 207–216). This Code of Practice for the repair of castings has been drawn up by Sub-Committee T.S.23 of the Institute of British Foundrymen. The following defects can be repaired by welding, burning on, or similar methods: (1) Foundry defects such as blowholes, draws, laps, scabs, misruns, short casts; (2) production defects such as machining and designing errors; and (3) service defects such as worn and broken castings. The factors limiting such repair include the extent of the defect, its location, the form of the casting, and the service conditions under which the casting operates. The methods available for such reclamation are oxy-acetylene welding, using ferrous or non-ferrous electrodes, metallic arc welding, and burning-on. Full preheating, at a temperature not exceeding 600° C., of the damaged casting enables gas fusion welding to be employed, but where this is not possible, and for the repair of minor faults, arc welding may be used. The correct preparation of the casting and the welding technique are fully indicated, and properly made welds have practically the same strength as the base metal. Burning on is preferable to welding when a substantial quantity of metal has to be added, but should only be considered for locations that will not develop serious local stresses in the casting. The metal composition should be such that chilling and brittleness in the burnt-on portion are avoided. Full particulars of the method advocated are given. High sulphur and high phosphorus contents are deleterious. Chromium and molydenum hinder satisfactory fusion and increase the hardening tendency in the affected zone.—J. E. W.

Brazing of Steel. S. L. Case. (Steel Processing, 1950, vol. 36, Mar., pp. 125–129, 161; Apr., pp. 183–185, 199, 206; May, pp. 238–243, 257, 265). The first part of this article describes torch, dip, electric, and furnace brazing techniques. Brazing alloys may be applied as powder, sheet, wire or by metallizing pistol. The design of butt, scarf, and lap methods of joining are described, and the various methods of flux application (powder, paste, liquid, and gas) are outlined. Part II deals with the wetting and surface tension of brazing alloys, and the effect of these two properties on the flow of the brazing alloy. The tension balance (Kollograph), capillary-rise, and maximum-bubble-pressure methods of determining surface tension are described. Part III deals with the metallurgy of brazing; the bond may be formed by grain-boundary penetration, alloying, or simple adherence of the brazing alloy. The latter condition is discussed in some detail, it being concluded that there always is a certain amount of atomic diffusion, although not sufficient to be observed microscopically. The strength of a brazed joint depends upon the film thickness of the brazing alloy, there being an optimum thickness above and below which the strength decreases. The author ends with a detailed discussion of the formation and deleterious effects of 'voids' in the brazing film. There are 15 references.

P. M. C.

The Development of Welding and Brazing of Cast Iron. Loix. (Pratique du Soudage, 1949, vol. 3, Dec., pp. 177–182). The author discusses the possibility of electric arc welding, oxy-acetylene welding, and brazing both white and grey cast iron, and stresses that it is very much cheaper to repair castings by welding them to obtain replacements. The metallurgical changes which take place in both types of cast iron when submitted to welding temperatures are described and it is shown how a knowledge of these fundamentals will determine the best form of welding procedure. Precautions to be taken in order to obtain a machinable weld are considered as well as various types of weld metal, amongst others nickel; copper and nickel; nickel, silicon and carbon; and tin and zinc. Examples are given of a number of medium and large castings which have been satisfactorily repaired by welding.—M. D. J. B.

Method for the Automatic Submerged Welding for Production of Plug Joints. V. V. Verchinskii and V. N. Dubov. (Avtogennoe Delo, 1948, No. 2, pp. 25–26). [In Russian]. Plug-welding procedure is briefly described, some examples being given of its applications and the increased productivity obtained. Illustrations show constructional plug-welded joints, a polished section through a typical joint, and their appearance after rupture in a testing machine.—S. K.

Choice of Equipment for Welding with a Three-Phase Arc. N. S. Siunov. (Avtogennoe Delo, 1948, No. 10, pp. 1–6). [In Russian]. Attention is drawn to the fact that the electrical industry of the U.S.S.R. has not provided satisfactory special equipment for 3-phase arc welding, although this method requires only 1·8–2·3 and 2·6–3·0 kWh. per gramme of metal melted for the automatic submerged arc and the manual processes respectively, compared with corresponding values of 2·5–3·0 and 3·2–3·6 kWh. for single-phase welding. Descriptions with circuit diagrams of methods for adapting ordinary welding transformers for 3-phase welding and of special adjustable 3-phase transformers proposed by the author are given. The performances of the various arrangements are compared, and oscillograms are shown. Wider application of 3-phase welding is called for.—S. K.

Methods for the Determination of the Main Parameters of the Process of Electrode Melting in Electric Arc Welding. A. A. Erokhin. (Avtogennoe Delo, 1948, No. 10, pp. 6–11). [In Russian]. Problems connected with the standardization of electrode testing are considered, and suggested standard welding conditions are listed for the determination of their principal parameters, characterizing the following: The weights of fused and deposited metal per unit of electrical charge; the weight of metal lost per unit weight of metal fused; the weight of coating per unit weight of electrode wire; the weight of slag formed over the weld per unit weight of coating melted. Several methods are given for the determination of each parameter, and, as an example, a set of experimental data and the necessary derived quantities are tabulated. These suggestions have received official approval.—S. K.

The Automatic Argon-Arc Welding of Thin Metals. A. Ya. Brodskii. (Avtogennoe Delo, 1948, No. 10, pp. 11–17). [In Russian]. Three designs of machine for automatic argon-arc welding of sheets 1–1·5 mm. thick are described. The first, incorporating a special holder, has discontinuous regulation of linear speed from 9 to 144 m./hr. and can execute straight welds from 750 to 2000 mm. long. The second, having an

ordinary manual electrode holder, is suitable for curved welding of small containers. The third is an adaption of a semi-automatic flame-cutting machine, which is provided with a special electrode holder, and, having continuous regulation of speed, is specially suitable for dealing with non-ferrous metals. Welding conditions are described for various types of welds, and it is stated that test pieces remained uncorroded after immersion for 720 hr. in sea water at 18–20° C. S. K.

The Control of the Distortion of Thin Sheets during Arc Butt Welding. N. N. Prokhorov. (Avtogennoe Delo, 1948, No. 10, pp. 17–20). [In Russian]. An account is given of experiments in which the deformations due to welding of low-carbon steel plates 700 × 400 mm. with thicknesses of 2, 3, and 4 mm. were measured. Measurements were made both of local deformation during the welding in areas of the metal at temperatures up to 900° C., and of residual deformations. It is concluded that deformation in a sheet bead-welded along one edge is due to temperature stresses and this can be reduced by a more uniform temperature distribution; the application of uniform pressure to the region parallel to the seam, and at a distance of two to five times the sheet thickness, is an effective way of reducing deformation.—S. K.

Automatic Submerged-Arc Welding of Steam Boilers at the 'First' of May Works. G. I. Brandobovskii. (Avtogennoe Delo, 1948, No. 10, pp. 20–23). [In Russian]. All-welded steam boilers have been produced at this factory without any rejects, using an automatic submerged-arc process. A low-carbon electrode was used with a flux consisting of SiO_2 45%, MnO 32%, CaO 10%, MgO 3%, and CaF_2 5·5%, giving a value of approximately 20 for the weight ratio of manganese to sulphur in the weld. A typical weld had the following mechanical properties: Tensile strength 47 kg./sq. mm.; elongation 25%; toughness 9·8 kg.m./sq. cm. A special welding stand with rubber-covered rollers enabled the boiler to be moved along its axis or to be rotated either in a horizontal position or tilted at 30°, with a maximum welding speed of 45 m./hr. The flux was produced at the same factory, and mention is made of difficulties encountered.—S. K.

Rapid Manual Electric Welding at the Molotov Works, Kuznetsk. L. B. Tsalman. (Avtogennoe Delo, 1948, No. 10, pp. 23–25). [In Russian]. An account is given of experiences since 1946 in the use of deep welding at the Molotov Works. The technique has been rapidly assimilated and has increased output by a factor of 1·5–2, the quality of welds obtained being up to specification. Best results were achieved with an electrode coating consisting of hematite, ferromanganese, feldspar, and water-glass, but special attention had to be given to the quality of these materials, the passivation of the ferromanganese, and the carbon content of the electrode wire. An oxy-acetylene flame was found to remove dirt and rust from the electrode or base metal, thus avoiding the formation of pores and cracks.—S. K.

Simple Methods for Surface Hardening with an Oxy-Acetylene Flame. A. N. Shashkov. (Avtogennoe Delo, 1948, No. 10, pp. 25–28). [In Russian]. An account is given of the flame-hardening of the external and internal crowns, the splines, and the two journal surfaces, 60–65 mm. wide, on a driving shaft 150 mm. in dia. Ordinary welding torches were employed, either singly or as two- or three-jet burners, together with a simple shielding device and a water spray. It was found that expenditure of gas under the given conditions was roughly proportional to the surface area of the hardened region and the square root of the depth of hardening. Results of hardness determinations at various depths below the surfaces are given and some macrosections of the hardened parts are shown.—S. K.

On the Question of the Reaction of Elements and Their Oxides in the Molten Weld Metal. K. V. Liubavskii. (Avtogennoe Delo, 1948, No. 10, pp. 30–31). [In Russian]. N. N. Dobrokhotov's recent article is said to include many conclusions at variance with the theory and practice of welding metallurgy, this being attributed to his assumption of the attainment of thermodynamic equilibrium and his underestimation of kinetic factors in slag–metal reactions.—S. K.

Post-War Graduations of Welding Specialists from the Bezhitskii Institute of Transport Mechanical Engineering. G. D. Shevchenko. (Avtogennoe Delo 1948, No. 10, p. 32). [In Russian]. Brief notes are given on some of the outstanding welding researches conducted by students at the above Institute since 1945.—S. K.

Thermal Efficiency of the Process of Melting the Base Metal by the Welding Arc. N. N. Rykalin. (Avtogennoe Delo, 1948, No. 11, pp. 1–7). [In Russian]. The distribution of arc-generated heat in the weld region and its utilization for fusion are compared for some ideal theoretical cases and for welding with unshielded and shielded metal arcs and with a carbon arc. The thermal efficiencies of bead welding on massive parts and on sheets of low-carbon steel 16–30 mm. thick, and the butt-welding of thin sheets are considered for various voltages, currents, welding speeds, and dimensions of fusion zones. The efficiency of utilization of arc heat increases with speed of welding and strength of current in the cases dealt with.—S. K.

The Nature of the Thermal Processes and the Dimensions of the Weld Spot in the Welding of Structural Steels. A. S. Gelman. (Avtogennoe Delo, 1948, No. 11, pp. 8–13). [In Russian]. A detailed examination is made of the relationship between the effective area of the spot weld and the thermal effects of the process producing it. Curves of shearing strength against time of welding for two steels are shown. An equation for the temperature distribution is deduced and used for calculating the diameter of the central portion of the spot weld and the depth of fusion, the results being in good agreement with experimental data for spot-welded specimens of low-carbon steel. The effects on extent of fusion of the force applied to the electrodes and of the area of contact are also examined.—S. K.

Determination of the Pressure on the Electrodes of a Spot-Welding Machine by Measuring the Deformation of Its Arm. A. Z. Blitshtein. (Avtogennoe Delo, 1948, No. 11, pp. 13–14). [In Russian]. Some of the common methods of applying and measuring the force on the electrodes of spot-welding machines are briefly considered. A method is described in which the force is measured by noting the changes in the distance from a fixed point on the lower arm to the base of the machine, the relation between the load and this distance having been previously established. It is estimated that with an indicator reading to 0·01 mm., the force on the electrodes can generally be measured with an accuracy of 2–5%. This method is also said to be suitable for finding the relationship between the force on the electrode and the pressure in the cylinder for pneumatically actuated machines. S. K.

The Alloying of the Deposited Metal in Electric Arc Welding. P. S. Elistratov. (Avtogennoe, Delo 1948, No. 11, pp. 18–19). [In Russian]. Chemical and metallographic studies of the different zones in the core of a used coated electrode and in the metal deposited, showed that the alloying of the molten metal of the electrode wire during the period of the formation and transfer of the drop is the process which mainly governs the alloying of the deposited metal. Thus, to increase the extent of alloying, the size of drop must be increased. The electrodes used consisted of a ferrite core, coated with mixtures of graphite (80–20%) and ferrosilicon (20–80%), with an outer slag-forming protective layer 0·5–0·6 mm. thick. Photomicrographs are shown of the different structures found.—S. K.

Technical Process for the Preparation of Copper–Chromium Alloy for the Electrodes of Spot-Welding Machines. I. M. Goryachev and E. A. Smirnova. (Avtogennoe Delo, 1948, No. 11, pp. 20–21). [In Russian]. The alloying of 0·5% of chromium with copper was found to triple the durability of spot-welding electrodes whilst decreasing the electrical conductivity by only 10%. The production of such alloyed electrodes by simple methods is described, and some of the properties are tabulated.—S. K.

Rapid Welding with Deep Penetration at the Molotov Works, Dniepropetrovsk. D. P. Lebed and D. V. Shatailov. (Avtogennoe Delo, 1948, No. 11, pp. 22–23). [In Russian]. On the basis of industrial experience, recommendations are made on the size of gap, electrode diameter, current strength, and welding speed for the deep-welding of plates 4–12 mm. thick. Examples are given of the satisfactory mechanical properties of deep-welded joints and of increased productivity following the introduction of this method at the Molotov Works.—S. K.

The Assembly of a Steam Boiler. V. G. Dolgikh. (Avtogennoe Delo, 1948, No. 11, p. 23). [In Russian]. A brief description is given of the successful welding of tubes in the manifold of a steam boiler designed to work at 22 atm. pressure. An oxy-acetylene torch was used with electrode wire

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4 mm. thick as the welding rod. The welds were made in two layers and normalized.—S. K.

Defects in Pressure Gas-Welding of Tubes. S. M. Skorodzievskii. (Avtogennoe Delo, 1948, No. 11, pp. 24–25). [In Russian]. Lip formation at the joint in the pressure gas-welding of tubes was investigated with the aid of tensile tests; this was found to decrease appreciably the tensile strength of the joint. Typical lipped and satisfactory joints are illustrated. The harmful effect of lip formation is attributed to heterogeneity of structure due to uneven heating.—S. K.

Melting Out and Welding Up of Flaws in a Steel Casting with an Arc. S. V. Begun. (Avtogennoe Delo, 1948, No. 11, pp. 25–26). [In Russian]. In the method described, inclusions are melted out from steel castings using an A.C. arc and a heavily coated electrode 4–8 mm. thick, the amperage used being 55 to 65 times the electrode diameter in millimetres. After mechanical cleaning, the cavities are welded up using the same type of electrode. The success of this technique is exemplified by the deseaming of a steel casting of the composition carbon 0·24%, manganese 0·84%, silicon 0·23%, sulphur 0·043%, phosphorus 0·035%, having a surface of pearlite and ferrite of Widmanstätten structure over partially recrystallized pearlite and ferrite. The deposited metal was ferrite with a small proportion of pearlite in a columnar dendritic structure, whilst the zone directly under the seam consisted of sorbitic pearlite and ferrite.—S. K.

Experience in the Incorporation of the Manufacture of Coated Electrodes in the Works of the Lenpromenergomontazh Combine. M. B. Eksler. (Avtogennoe Delo, 1948, No. 11, p. 27). [In Russian]. A very brief account is given of the fully mechanized equipment of a new plant for the production of coated electrodes for arc-welding.—S. K.

Automatic Submerged-Arc Welding in Construction. V. S. Volodin and B. I. Iurgel. (Avtogennoe Delo, 1948, No. 12, pp. 1–4). [In Russian]. An account is given of the successful introduction of automatic submerged-arc welding for the construction of oil storage tanks on site, and an outline is given of some proposed further applications of this technique. The use of a head with a roller on an insulated spindle was found to be the best method for directing the carriage, and some improvements for the standard designs of these machines are suggested. Welding currents, voltages, electrode diameters, and rates of feed for metal thicknesses of 4, 5, and 6·5 mm. are tabulated. Welds obtained using three different fluxes are compared.—S. K.

Experience in the Application of Automatic Welding in the Manufacture of a Tender. V. V. Danilevskii. (Avtogennoe Delo, 1948, No. 12, pp. 5–6). [In Russian]. A description is given of the equipment and conditions of welding used for the submerged-arc welding of the water tanks of locomotive tenders. Whilst with manual welding two of the operations took about 2¼ and 4 min. and cost about 7 and 11 roubles, respectively, the corresponding figures for the automatic process were 24 and 18 sec. and 1 and 0·7 roubles.—S. K.

Treatment of Components for the Manufacture of Thickly Coated Arc-Welding Electrodes. N. Kriukovskii. (Avtogennoe Delo, 1948, No. 11, pp. 6–8). [In Russian]. Recommended conditions for the various stages in the preparation of the following components of electrode coatings are described: Titaniferous concentrate; manganese ore; feldspar; ferromanganese, ferrosilicon, ferrotitanium, ferrochromium, and ferromolybdenum; marble; fluorspar; kaolin; forge cinder; quartz; and starch, dextrin, and flour.—S. K.

Rational Type of Equipment for the Fine-Crushing of Electrode Materials. N. M. Sergeev. (Avtogennoe Delo, 1948, No. 12, pp. 8–10). [In Russian]. Seven types of crushing machine for use in preparing electrode coating materials are described and their performance and products are compared.—S. K.

Electrodes for Hard-Facing a Cutting Tool. V. A. Lapidus. (Avtogennoe Delo, 1948, No. 12, pp. 13–16). [In Russian]. Two types of coated electrode were evolved to give deposits with martensite and ledeburite eutectic structures with Rockwell C hardness of 62–65 and the following respective compositions: Tungsten 17·5–19 and 8·5–10%; vanadium 1·0–1·4 and 2·0–2·6%; chromium 3·8–4·5 and 4·0–4·6%; carbon 0·7–0·8 and 0·85–0·95%; silicon 0·4 and 0·45%; and manganese 0·4 and 0·45%. To find the mechanism of the alloying process investigations were made of the various stages of drop formation and the properties of separate drops from the electrode, of a bead of the deposited metal, and of samples of spatter: most of the alloying was found to be taking place at the end of the electrode. The electrode wire used could be either low-carbon, high-carbon, or alloyed, the coating being applied in three or four stages with intermediate air-drying and calcining at 350–400° C. Cutting tools could be produced more cheaply with these electrodes than with Kontorov's electrodes, the performance of the tools being entirely satisfactory.—S. K.

Deformations and Stresses in Intermittent Welding. N. O. Okerblom and I. P. Baikova. (Avtogennoe Delo, 1948, No. 12, pp. 16–20). [In Russian]. The results of a theoretical investigation of the deformation and stresses produced during the welding of short seams are applied to the conditions of intermittent arc-welding with welding currents of 150 amp., voltages of 20, and welding speeds of 0·12 cm./sec. Calculated 600° isotherms are drawn and the variations in size and shape of the zones at higher temperatures are considered. The effects of the relative dimensions of bead, strip, and interbead interval on deformation and stress for the case of intermittent bead-welding along the edge of a strip are examined, and the significance of fluctuating temperature conditions is discussed for various methods of depositing the seam.—S. K.

Decreasing Deformation by Peening during Welding. V. M. Rybakov. (Avtogennoe Delo, 1948, No. 12, pp. 20–21). [In Russian]. In the investigation described, a bead was welded along one of the long sides of a rectangular steel specimen 500 mm. × 110–140 mm. × 8–12 mm. Submerged arc and coated electrode processes were used, and the specimens were subjected to hand peening at a temperature of 15° C. or 150–200° C., the deformations at various distances from the beaded edge being determined. The effectiveness of peening was found to increase with decreasing expenditure of electrical energy for producing unit length of weld. With standard welding conditions and peening procedure the effect of peening was found to depend on the type of steel, the degree to which deformation was removed varying from 53% to 25%.—S. K.

Stress Changes in the Welding Process. I. P. Trochun. (Avtogennoe Delo, 1948, No. 12, pp. 22–23). [In Russian]. Stress-temperature diagrams are developed for temperature conditions existing during welding, and the growth of residual stresses is related to the plastic properties of the material being welded.—S. K.

MACHINING AND MACHINABILITY

Profiling and Turning of Milling Cutters by the Anode Mechanical Method. G. S. Bielajew. (Przeglad Techniczny, 1950, July–Aug., pp. 379–381). [In Polish]. Some experiments in metal working by the anode mechanical method are described.—V. G.

Types of Oxidation of a Metallic Alloy when Ground at Different Speeds in a Rarefied Atmosphere. R. Courtel. (Revue de Métallurgie, Mémoires, 1950, vol. 47, Sept., pp. 700–703). A nickel–chromium alloy (Ni 80%, Cr 20%) was ground at various speeds in air at 8 cm. Hg pressure and the surface examined by electron diffraction. At speeds around 50 ft./sec. only NiO was detected, with Cr_2O_3 appearing at speeds above 80 ft./sec. These 'oxidation thresholds' can be related to similar behaviour with purely thermal oxidation. However, by grinding clean surfaces the duration of reaction is short with no induction period, so that ionic diffusion is unimportant.—A. G.

Conditioning Surfaces of Large Housings in Place. E. A. Berry. (Iron and Steel Engineer, 1950, vol. 27, Sept., pp. 110–112). A description is given of special grinders which can be fitted to large mill housings which cannot be readily taken down and moved to the repair shop. The castings are re-surfaced with nickel–chromium welding wire making machining by methods other than grinding very difficult. Parallelism of 0·031 in. in 18 ft. was obtained with the equipment described.—M. D. J. B.

Grindability of Tool Steels. L. P. Tarasov. (American Society for Metals, Oct., 1950, Preprint No. 42). Grindability is defined as the ratio of volume of material removed to wheel wear, and this index was found for various steels. Curves of the energy used in grinding against the index show the relative importance of relevant factors. For steels of the same hardness range the most important factor is the hardness of the carbide constituent. Chromium and vanadium lower the index, and so does an increased Rockwell hardness.

E. T. L.

Friction Cutting of Steel. J. E. Hyler. (Steel Processing, 1950, vol. 36, June, pp. 295–310). Both circular and bandsaw friction cutting techniques are described. Steel heated to 1400° F. can be cut with only one-sixth of the energy required for the cold process. Circular saws, between 24 and 48 in. in dia., run at 18,000 ft./min. for heated stock and from 20,000 to 28,000 ft./min. (peripheral speeds) for cold work. Rim tension is induced by hammering the centre of the saw blade area. Bandsaw friction cutting is used for contouring relatively thin stock, typical speeds being 3000 ft./min. for a $\frac{1}{16}$-in. blade and 15,000 ft./min. for a 1-in. blade.—P. M. C.

Use the Right Machining and Drawing Fluids to Improve Production Efficency. E. L. H. Bastian. (Steel, 1950, vol. 126, May 29, pp. 58–62). The author outlines the essential differences between active and inactive oils, gives advice on the selection and application of cutting and grinding fluids and cutting oils, and explains their function. A table is included giving recommended fluids for various operations on different materials.—A. M. F.

A Machinability Test for Treated Cast Iron. E. A. Loria and R. L. Keller. (Iron Age, 1950, vol. 165, June 1, pp. 73–76). The Mellon Institute of Industrial Research have carried out tests to evaluate the improvement in machinability of thin sectioned grey iron castings by the use of Ferrocarbo silicon carbide as a cupola addition agent. Increased tool life was found to be 50–100% over the average tool life for other irons tested for the same specific power consumption.—A. M. F.

Tools for High-Speed Cutting Machines. W. Szymanowski. (Przeglad Techniczny, 1950, May, pp. 236–240). [In Polish]. A brief historical survey is made of machine tools, and present requirements for high-speed cutting are outlined.—V. G.

Edge Durability in High-Speed Machining. A. Yozefik. (Przeglad Techniczny, 1950, May, pp. 241–244). [In Polish]. The general relationship between edge durability and speed of cutting is presented. The materials used for cutting tools are surveyed and the influence of the geometrical forms of cutting edges on their durability is discussed.—V. G.

CLEANING AND PICKLING

Action of Inhibitors in the Acid Pickling of Steel. Part II. M. Smialowski, J. Synowiec, and M. Szota. (Prace Badaweze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 1, pp. 31–35). [In Polish]. No satisfactory results were obtained when various structural steels were pickled in sulphuric acid at 40° C. using dibenzylsulphide as an inhibitor. With mixed powders of electrolytic iron, nickel, and copper the inhibiting efficiency of dibenzylsulphide is greater than with iron powder alone or with iron and graphite. The adsorption of aniline and diphenylamine by electrolytic iron powder was tested by experiments; they had very feeble inhibiting action on steels in sulphuric acid.—R. A. R.

The System $FeSO_4-H_2SO_4-H_2O$ at 50–90° C. A. P. Belopol'skiy and S. Ya. Shpunt. (Iron and Steel Institute, 1950, Translation Series, No. 409). This is an English translation of a paper which appeared in Zhurnal Prikladnoy Khimii, 1941, vol. 14, No. 6, pp. 716–733. The solubilities in the system $FeSO_4-H_2SO_4-H_2O$ are of interest in the utilization of waste pickling liquor. These have been investigated at temperatures of 50°, 60°, 70°, and 90° C. The 50° isotherm, studied at H_2SO_4 concentrations up to 91·3% consists of portions corresponding to $FeSO_4.7H_2O$, $FeSO_4.4H_2O$, $FeSO_4.H_2O$, and $FeSO_4$. The 60° isotherm consists of portions corresponding to $FeSO_4.4H_2O$, $FeSO_4.H_2O$, and $FeSO_4$. The 70° and 90° isotherms consist of portions corresponding to $FeSO_4.H_2O$ and $FeSO_4$. Contrary to the results obtained by Cameron, these authors find that the dihydrate $FeSO_4.2H_2O$ does not constitute a stable phase either in the binary $FeSO_4$-H_2O or in the ternary $FeSO_4$-H_2SO_4-H_2O system.—R. A. R.

PROTECTIVE COATINGS

Studies on Marine Fouling Organisms. K. A. Pyefinch. (Journal of The Iron and Steel Institute, 1950, vol. 165, June, pp. 214–220). This paper summarizes the work which has been done on the biological aspects of the fouling problem, mainly at Millport (Firth of Clyde) during the period 1944–48. Much of this work has been published in the appropriate biological journals.

A continuation of non-toxic panel exposures, both at Millport and elsewhere, has added fresh details to what was known about the seasonal sequence of settlement and emphasized the extent of variations in density of settlement from year to year. Laboratory determinations of the sensitivity of most of the major fouling organisms to copper and mercury have revealed many complexities in this phenomenon which, it is suggested, can only be resolved by fundamental studies of the action and interaction of these poisons. Many observations have been made on the general biology of a number of animal fouling organisms. The ecology of their interrelationships, and of their relationships with marine plants, deserves further study.

Performance of Anti-Corrosive Compositions in Sea Water—Effect of Surface Preparation of Steel. J. C. Hudson. (Journal of The Iron and Steel Institute, 1950, vol. 165, July, pp. 314–334). The paper presents and discusses the results of the Marine Corrosion Sub-Committee's researches which show that different methods of surface preparation have a marked effect on the performance of anti-corrosive compositions in sea water.

Paint gives poor protection against exposure to sea water if applied over millscale. Since, however, some paints fail to adhere to a completely descaled, freshly prepared, and unrusted steel surface, it is recommended that the descaled steel surface be allowed to rust slightly or be treated with phosphoric acid wash before the application of the priming coat of anti-corrosive composition. In the case of ships' hulls, weathering the steel plates until they have shed their millscale completely should therefore yield good results. In practice it is difficult to ensure complete descaling of all the component plates of a ship's bottom, and descaling of the plates by grit-blasting or by pickling, followed by a short weathering period or treatment with a surface wash is recommended.

Rates of pitting up to 0·16 in./yr. have been observed at 'holidays' (bare areas in a paint film) on an immersed steel plate. The presence of intact millscale beneath the paint may also promote pitting, but if about 90% of this is removed by weathering, pitting will probably be no more severe than when the millscale is removed by pickling. The procedure of launching a ship with the bottom unpainted is not recommended because, owing to the slower removal of millscale, pitting may result; it is also difficult to clean the surface before painting.

With a few exceptions, the relative behaviour of a given set of bottom painting schemes is the same whether applied to new specimens of unpainted steel or to specimens which have previously been painted and exposed to an immersion test. This applies in the main to both the protective and anti-fouling properties of the painting schemes.

Formulated anti-corrosion compositions developed by the Marine Corrosion Sub-Committee give good results as priming paints under a bottom painting scheme. A mixed red lead and white lead paint in linseed oil is less satisfactory, although much better than a red iron-oxide paint in linseed oil. Zinc or aluminium coatings on steel improve the performance of bottom painting schemes applied over them; lead, however, promotes pitting. Results of a raft test and those of a patch-painting trial are in good agreement.

Corrosion Protection of Iron and Steel Surfaces. J. C. Hudson. (Metallurgia Italiana, 1950, vol. 42, Mar., pp. 85–95). The author describes the experimental methods and equipment used for atmospheric corrosion tests of wrought iron and steel bars, painted or coated with metals, used by the Protective Coatings Sub-Committee of the British Iron and Steel Research Association. He also reports the results obtained during the first 20 years of operation of the experimental station. These results show the importance of good surface preparation, the methods of painting, and the thickness of the coatings. Good results could be obtained from coatings on mill scale if it were intact. The process of flame cleaning is also described.—R. F. F.

POWDER METALLURGY

New Type of Stainless Steel Powder Develops High Green Strength. G. Stern. (Materials and Methods, 1950, vol. 32, July, pp. 52–54). Further particulars are given of the two stainless powders described previously (*see* 'Use of the Transverse Rupture Test to Evaluate a New Stainless Steel Powder,' Journ. I. and S.I., 1950, vol. 166, Sept., p. 98). One contains 14% Cr, (balance iron), and the other 17–18% Cr and

8–9% Ni. These powders have remarkably good green strength after pressure compacting before the usual sintering process. Typical transverse rupture strengths after compacting at 45 tons/sq. in. are 4580 lb./sq. in. and 3030 lb./sq. in. respectively, whereas the values for two ordinary commercial powders under the same conditions of test are 350 and 859 lb./sq. in. The shrinkage, density, hardness and tensile properties of both materials after final sintering are fully described and tabulated. The properties of the 14% Cr grade when infiltrated with silver and copper are also given.—P. M. C.

Powder Parts Invade the Appliance Field. D. W. Lynch and T. J. Snodgrass. (Iron Age, 1950, vol. 165, June 8, pp. 83–86). The General Electric Company of America is using powdered high-strength iron impregnated with copper for gears to replace malleable iron castings in the gear train of an automatic washing machine. The mix is nominally 1·00% total carbon, up to 30% absorbed copper and the balance essentially iron. Savings of 60–70% are claimed.—A. M. F.

Some Practical Considerations on Cemented and Sintered Carbide Products in Relation to their Mechanical Working. C. A. Bertella. (Metallurgia Italiana, 1950, vol. 42, Aug.–Sept., pp. 299–304). The composition and characteristics of sintered carbides for cutting tools are briefly reviewed. The various methods of attachment to machines and the correct use of machine tools are examined. The author mentions the comparative scarcity of sintered carbide products in Italy and suggests the lines along which progress in this field should develop. A study is made of the best type of cutting tool, the care of tools, and of the most suitable machines for use with carbide products.—M. D. J. B.

The Retractometer, an Apparatus for the Study of Sintering and Reactions in the Solid State. S. Tacvorian and M. Lévecque. (Comptes Rendus, 1950, vol. 231, Oct. 16, pp. 772–774). Changes in volume up to 1800° C. are transmitted *via* a sintered alumina rod to a lever system (amplification 7·5) and are registered on a drum as a function of temperature. Sensitivity is 0·1% change in length. The apparatus has been used to study the sintering of refractory powders such as kaolin, solid–gas reactions, *e.g.*, action of nitrogen on chromium, and allotropy.—A. G.

Assessing the Behaviour of Compacted Iron Powders by Bend Tests. H. Bernstorff and F. Moser. (Stahl und Eisen, 1950, vol. 70, May 11, pp. 416–420). Previous methods of assessing the behaviour of compacted iron powders are reviewed and the construction of a machine suitable for measuring the transverse strength of pressed, unsintered test pieces is described. The test proved itself to be well adapted for the evaluation of the properties of pressed iron powders which require to be known and controlled in mass-production powder-metallurgy methods. It is sensitive to all those factors (grain size and distribution, carbon content, and superficial oxidation) which influence the industrial suitability of a pressing. The results of tests on powders annealed for various times and at various temperatures show that the decrease in carbon and oxygen contents is reflected in an increased transverse strength. When small amounts of graphite are added to iron powder, there is a marked decrease in the green strength of the pressings, which is not appreciably affected by further additions of graphite. This is in contrast to the density of the pressings, which are hardly affected by the presence of graphite. It is difficult to lay down a value of the transverse strength as a minimum for general use, since much depends on the shape and size of the part actually to be made. In general, it may be said that objects made from iron powders with transverse strengths, in the green state, of less than 0·5 kg./sq. mm. under a pressing load of 2 tons/sq. cm. will not retain sharp contours and edges under normal industrial working conditions.—J. P.

Powder Metallurgy, Hard Sinters without Tungsten Carbide. H. Rutkowska. (Hutnik, 1950, vol. 17, No. 7–8, pp. 263–264). [In Polish]. A short survey of hard sinters (not containing tungsten carbide) suitable as materials for cutting tools, and trends in their development are given.—V. G.

PROPERTIES AND TESTS

Fractographic Registrations of Fatigue. C. A. Zappfe and C. O. Worden. (American Society for Metals, Oct., 1950, Preprint No. 32). Experiments on 75*S*-*T*6 aluminium alloy, mild steel, and alloy steel show two distinct patterns at the fracture, apparently representing respectively a preliminary (which is called 'platy') and a final stage ('fine lamellar'). The patterns show a mosaic constitution, with a structural reorganization due to fatigue. This explains the increase of damping with onset of fatigue, and promises insight into fatigue; a tentative explanation is offered based on the new 'micellar theory' of the solid state.—E. T. L.

A Center Quenched Hardenability Bar for Shallow Hardening Steels. E. J. Eckel. (Metal Progress, 1950, vol. 57, Apr., pp. 474–476). The author describes a new test using a simple test bar consisting of a rod drilled longitudinally off centre. It is quenched internally and the varying cross-section results in different cooling rates near the outer surface. Tests on specimens show good reproducibility of hardness distribution, the method makes the heat-treating atmosphere unimportant, and the test is cheaper than the usual forming test.—E. T. L.

Hardness Variations in Carbon–Molybdenum Steels after Tempering. R. D. Chapman and W. E. Jominy. (Metal Progress, 1950, vol. 57, Apr., pp. 491–496). The results cited here make it possible to predict the range of hardness of certain steel rods after tempering, whereas previous results have dealt with the hardness of an as-quenched steel. Rockwell hardness testing showed the decrease during tempering of six molybdenum steels, also that martensite softens more than bainite, and bainite more than pearlite. Microstructure examination also revealed that a low-carbon steel with the same as-quenched hardness as a high-carbon steel will soften more during tempering above 800° F.—E. T. L.

The Comparability of Results of Hardness Measurements. J. Wozniacki. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 3, pp. 197–221). [In Polish]. The concept of hardness, its practical applications, methods of numerical representation, and the possibility of comparison of measurements made by different methods are discussed. Attention is drawn to the inadequacy of indenter determinations of hardness. A number of factors which have an influence on hardness measurements, such as deformation, load on penetrator, etc., are given. The possibility of comparing hardness numbers obtained by the Brinell, Ludvik, and Vickers methods is discussed.—V. G.

A Hardenability Test for Deep Hardening Steels. W. Wilson, jun. (American Society for Metals, Oct., 1950, Preprint No. 18). A new criterion of equivalent cooling conditions is proposed for the correlation of hardenability tests with the cooling curves measured during actual quenching. Equivalent cooling conditions exist only when the cooling curves may be superimposed between the upper critical temperature or the solution temperature—whichever is the lower—and the M_s temperature. Hence a hardenability test was designed for deep-hardening steels to reproduce oil quenching, suitable for steels less than 21 in. in dia. Operational details and representative results are given of this new test method.—E. T. L.

The Why and How of Cold Hardness Measurement. J. H. Hruska. (Iron Age, 1950, vol. 165, June 1, pp. 77–80). Inconsistent results of previous experimenters are attributed to undercooling and variations of temperature. The author has equipped standard testing instruments with auxiliaries to give controllable and uniform heat transfer from sample to coolant. Graphs are given for the Brinell hardness of copper, aluminium, magnesium, and iron from + 75° F. to — 100° F. and for lucite, rubber, and two types of neoprene down to — 80° F. A. M. F.

Grain and Grain-Boundary Compositions: Mechanism of Temper Brittleness. J. W. Spretnak and R. Speiser. (American Society for Metals, Oct., 1950, Preprint No. 21). The theory of the thermodynamics of interfaces and surface adsorption of solute atoms is examined. It is shown that the amount of solute atoms at grain boundaries can be explained by the adsorption isotherm, and a formula is derived for the effect of temperature. Brief experimental study of positive adsorption of carbon atoms at the austenite grain boundaries leads to a new theory of the mechanism of temper brittleness. During the quench the grain-boundary material becomes retained austenite, precipitating carbides on subsequent tempering and leaving fresh martensite on cooling to room temperature. It is suggested that embrittlement is caused by a thin layer of martensite in the grain boundaries, acting as a stress barrier. Alloying elements delay the carbide precipitation and enhance the resistance to tempering of the grain-boundary martensite.—E. T. L.

Effect of Strain Rate on Toughness of Temper Brittle Steel. D. C. Buffum and L. D. Jaffe. (American Society for Metals, Oct., 1950, Preprint No. 22). The effect of a change in strain rate upon the transition from ductile to brittle fracture was investigated. SAE 3140 steel was studied in the temper-brittle and in the unembrittled states. V-notched Charpy specimens were tested over a range of temperatures at two strain rates differing by 5,000,000:1. Contrary to a report in the literature, the transition temperature was found to be affected by the strain rate for both states.—E. T. L.

Rheotropic Embrittlement of Steel. E. J. Ripling and W. M. Baldwin, jun. (American Society for Metals, Oct., 1950, Preprint Nc. 24). 'Rheotropic embrittlement' is caused by severe service conditions, and is overcome by cold-working under mild service conditions. Testing the notch ductility of S.A.E. 1340 steel specimens after different degrees of pre-strain and tempering temperature suggests that brittleness at low temperatures can be partly removed by cold-work at higher temperatures. This rheotropic embrittlement was found to cause dangerously high transition temperatures in a heat-treated steel, and in annealed steels.—E. T. L.

Embrittlement of Stainless Steel by Steam in Heat-Treating Atmospheres. C. A. Zapffe and R. L. Phebus. (American Society for Metals, Oct., 1950, Preprint No. 25). It is found that steam causes considerable embrittlement, detected by finding the angle of bend sustained without fracture. Steels which sustain bending through 180° when hardened from a dry atmosphere, fail at 20° when steam is in the furnace atmosphere during heat-treatment. These results confirm a theory of the 'hydrogen potential' of steam–metal reactions. Attention is called to practical and theoretical consequences.
E. T. L.

Testing of Steel Ropes by an Electromagnetic Method. J. Furch. (Baňský Obzor, 1950, vol. 4, June, pp. 94–95). [In Czech]. An improved method of electromagnetic examination for steel ropes is described. The measuring coil consists of two series-connected half coils which are screwed together during testing. The rope is magnetized by an electromagnet with split pole pieces which are screwed together after insertion of the rope. The metering coil is fixed to the magnet by a metal plate to prevent any movement of the measuring coil relative to the magnet during tests. The voltages induced in the measuring coil are amplified electronically and fed to the grid of a thyratron which functions as a sensitive relay and can be set to operate only for voltages corresponding to a certain minimum damage in the rope. By this method a testing speed of 1 to 2 m./sec. is obtained.—E. G.

Stainless Steel Recording Wire. R. E. Koontz. (Wire and Wire Products, 1950, vol. 25, Sept., pp. 730–732, 763–764). Standard 0·0036 in. dia. stainless steel recording wire is manufactured by the National Standard Co., Niles, Michigan, to the specification agreed upon together with the Armour Research Foundation. The processing of the wire, selected after pilot-plant and laboratory tests on processed wire, consists of 14 separate controlled drawing and heat-treatment operations and six strict laboratory tests, and takes about six week to complete. Brief definitions of the desired magnetic characteristics are given, but no information on the details of the drawing process is proffered.—J. G. W.

Calculation of Curie Constant for Ferromagnetics and Paramagnetics Based on the Theory of Intermittent Activation. R. Forrer. (Comptes Rendus, 1950, vol. 231, Nov. 20, pp. 1130–1131). Activation entails the transfer of an electron pair from the $3d$ to the $4s$ or $4p$ state setting up a supplementary moment. The Curie constant C_e is obtained as the sum of C^i (value during activation) and C'^i ^{b} (value for rest of time). For iron $C_e = 1·245$, in good agreement with the experimental value 1·26 obtained by extrapolation for FeSi, FeAl, FeSn, and FeV alloys. The multiplicity of moments in paramagnetics can be partly explained by intermittent activation.—A. G.

Coercive Field of Separate Grains and Continuous Ferromagnetics. L. Weil. (Comptes Rendus, 1950, vol. 231, Oct. 23, pp. 829–831). In small grains magnetism changes by rotation of spin assemblies; in continuous media by displacement of Bloch surfaces. The theories of Néel for the coercive field have been applied to the two cases and the transition from one to the other studied by slowly sintering powders. An expression governing the evolution of the coercive field of an agglomerate with temperature is obtained and verified for iron–nickel alloys with 9–49% iron.—A. G.

Structure of Permanent Magnet Alloys. A. H. Geisler. (American Society for Metals, Oct., 1950, Preprint No. 9). X-ray diffraction analyses show that heat-treatment causes precipitation in Cunico, Curife, Silmanal, Vectolite, and all the Alnicos, and causes order–disorder transformation in Vicalloy. All these changes involved the formation of fine plate-like particles of a new phase which had initially an anisotropically strained crystal lattice. Cobalt decreased the difference in lattice parameter of the decomposition products; titanium increased it. Permanent magnetism was attributed to the fine, strained particles, which are aligned with the lateral dimensions parallel to one of the three cube planes of the matrix, in all but Alnico 5. There are 41 references.—E. T. L.

Ultrasonic Testing of Gas Turbine Disks. (Metal Progress, 1950, vol. 57, Apr., pp. 468–473). Results of tests of 22 blanks of 16% chromium, 25% nickel, 6% molybdenum steel for gas-turbine wheels, to correlate ultrasonic inspection results with microstructure are presented. It is concluded that ultrasonic inspection is satisfactorily sensitive to small internal discontinuities.—E. T. L.

The Dimensional Behaviour of Invar. B. S. Lement, B. L. Averbach, and M. Cohen. (American Society for Metals, Oct., 1950, Preprint No. 39). Dimensional changes during ageing of Invar have been studied as functions of time, temperature, heat-treatment, and chemical composition. After a quench-anneal, stress relief causes a contraction, while prolonged ageing between 20° and 95° C. causes a lattice change leading to expansion. X-ray diffraction shows 0·18% carbon is soluble at 830° C.; almost all carbon exists as graphite at room temperature. A heat-treament giving a small expansion coefficient has been devised. It is: Hold at 830° C. for 30 min., water quench; hold at 315° C. for 1 hr., air cool; and at 95° C. for 2 days and air cool.—E. T. L.

Formula and Nomogram for Determining the Strength of Steels in Relation to Carbon and Manganese Contents. A. Palazzi. (Metallurgia Italiana, 1950, vol. 42, Oct., pp. 361–365). Many formulæ have been suggested for the determination of the strength of steels based on chemical composition. It is doubtful, however, whether these formulæ are always satisfactory and readily applicable. The author suggests a new simple and practical method for assessing the strength of steels which can be adapted to particular cases and which enables the limits of accuracy to be forecast. The method is described and illustrated by an example in which the variables are the carbon and manganese content. It is stressed that the principle can be extended to cover all variables.—M. D. J. B.

Accelerated Life Tests for Fe–Cr–Al Alloys for Resistors. M. Signora and F. Baldi. (Metallurgia Italiana, 1950, vol. 42, July, pp. 255–260). A brief review is given of the methods of carrying out accelerated life tests on metallic alloys for resistors. A detailed description is also given of a series of tests based on the A.S.T.M. B76-39 standards for determining the best experimental technique for Fe–Cr–Al alloys. The authors suggest that the tests should not be conducted to the ultimate breaking of the wire but should be stopped when the resistance has reached a determined increase. The possibility is considered of obtaining a 'constant' from the tests which is independent from experimental procedure.—M. D. J. B.

Symposium on the Metallurgy of the Internal Combustion Engine. Part I. L. Riddle. (Australasian Engineer, 1950, Sept. 7, pp. 48–53). The author considers the metallurgical details of the following car engine parts: Crankshafts, connecting rods, camshafts, valve-operating mechanisms, bearings, and high-tensile bolts. The service requirements and the features underlying the design of all these components are outlined, and the types of steel used by nine different car manufacturers for each part are tabulated, together with heat-treatments and resulting hardnesses.—P. M. C.

Standardization of Tool Steels in Sweden. R. Arpi. (Metal Progress, 1950, vol. 57, May, pp. 643, 678). A table gives the approximate compositions of 18 tool steels standardized in Sweden, and their Brinell hardness maxima with the American Society for Metals equivalents.—E. T. L.

Specification for Pressure Vessel Steels. (Costruzioni Metalliche, 1950, vol. 2, Mar.–Apr., pp. 20–22). [In Italian]. This article gives a summary of a specification for high-grade steels for pressure vessels. Hot-rolled steels are considered; the impurities and thickness tolerances are given and the quality tests laid down. These include both tension and cold-bending tests for a range of steels. Specifications for steel tubes with

external diameters up to 200 mm. are also given and cover quality control and the technique of testing. Minimum values for hydraulic pressure testing and expansion are also given. M. D. J. B.

Some Tests on Relaxation of Cast Iron. V. T. Malcolm and S. Low. (American Foundrymen's Society, May, 1950, Preprint No. 50-9). The relaxation test, carried out by means of the equipment described, is a constant strain test, *i.e.*, the sum of the elastic and plastic strain is held constant. An extensometer is so arranged as to permit the stress to decrease when the strain attempts to increase. This is accomplished by opening a solenoid valve in the hydraulic load tank in which the head of water may be directly converted to stress on the test bar. The relaxation properties of the following two cast irons were determined: (1) A.S.T.M. specification A126-46T. Cl. B, with a tensile strength of 30,000 lb./sq. in.; (2) A.S.T.M. A48-46T. Cl. 50, alloyed, having a tensile strength of 50,000 lb./sq. in. At 1050° F., the first hour relieved approximately 70% of the stress. The effects of various stress-relieving treatments on the room-temperature tensile properties are shown graphically.—E. J. D. S.

Growth of Nodular Cast Iron. T. Ko. (Foundry Trade Journal, 1950, vol. 88, Apr. 20, p. 433). After repeated heating in air at 900° C. magnesium-treated nodular cast iron had 'grown' only one quarter as much as ordinary grey iron. Whilst excessive oxidation occurred in the grey iron, there was only slight decarburization at the surface of the nodular iron. Growths of ordinary and nodular grey iron after 550 hr. at 550° C., amounted to 0·6% and 0·45% respectively.—J. E. W.

High Strength (Nodular) Ni-Resist. Bradley and Foster, Ltd. (Bradley's Magazine, 1950, Dec., pp. 3–5, 8). Ni-Resist treated before casting with about 1% of cerium gives an iron alloy with over two and a half times the tensile strength and twice the transverse strength of standard Ni-Resist. It has considerable ductility and will withstand shock to a much better degree. The improvement is brought about by a change from flake to nodular graphite. This change was not, however, complete in any of the specimens examined. Ni-Resist treated with magnesium–nickel alloy gave only a small improvement in mechanical properties. The amount of magnesium necessary to bring about the optimum increase in properties was small, roughly one third that of cerium.—R.A.R.

Nodular Cast Irons. J. E. Rehder. (Department of Mines and Resources: Canadian Metals, 1950, vol. 13, May, pp. 16–20, 46, June, pp. 16–18, 21, 46, 47). Production and properties of nodular cast irons are contrasted with those of grey cast iron and malleable iron. Nodular cast irons contain free carbon only as smooth spherical graphite nodules. These form during solidification of the cast, due to magnesium additions, Cu–Mg, Ni–Mg, and Fe–Si–Mg alloys being most commonly used. High tensile strength and ductility are obtained with carbon contents of 3·30–3·80% so that advantage can be taken of the good fluidity, lower melting and pouring temperatures, and decreased shrinkage of high-carbon irons. Nodular cast iron characteristically contains 0·03–0·06% of magnesium, 2·50–3·00% of silicon, and the lowest possible amounts of sulphur, manganese, and phosphorus. Characteristics and use of the magnesium agents are described, also control methods and the use of silicon-bearing graphitizers as post-inoculants to improve nodulization and prevent formation of primary carbide. Foundry behaviour of nodular cast iron is dealt with, and its properties and heat-treatments are considered in some detail. Suitable fields of application are suggested.—E. C.

Gray Iron Preferred for Large, Heavy Duty Crankshafts. A. Finlayson. (Materials and Methods, 1950, vol. 31, June, pp. 69–71). The low notch-sensitivity, high damping, and improved strength properties of properly processed and inoculated grey iron make it suitable for diesel engine components, particularly large crankshafts which may be up to 18 ft. long and 5000 lb. in weight. A suitable material for these large castings has the following composition: 2·65% C, 1·40% Mn, 0·03% each S and P, 1·95% Si, 1·00% Mo, and 2·10% Ni. After heat-treatment, the average mechanical properties of integrally cast test bars will be: Tensile strength 70,000 lb./sq. in., transverse strength 15,500 lb./sq. in., endurance limit 35,500 lb./sq. in., modulus of elasticity in tension $22{\cdot}3 \times 10^6$ lb./sq. in., in shear $9{\cdot}8 \times 10^6$ lb./sq. in., and Brinell hardness 275. The metal in the actual shaft is usually found to be superior to that in the test bars. Shrinkage allowances when patternmaking range from $\frac{1}{16}$ to $\frac{1}{8}$ in. per foot. The advantages of iron casting over steel forging are briefly outlined.—P. M. C.

Tests Prove Worth of Cold Extruded Bolts. A. S. Jameson, J. A. Halgren, and S. A. Sheridan. (Iron Age, 1950, vol. 165, June 22, pp. 81–84; June 29, pp. 72–75). Cold-worked, double-extruded, rolled-thread, hexagon-head bolts are cheaper to produce than the quenched and tempered variety. Comparisons are made of bolts made from annealed and cold-drawn wire of 0·30–0·45% C with 0·60–1·00% Mn. The cold-worked bolt can be used up to $\frac{5}{8}$ in. in dia. and 6 in. in length without heat-treatment to meet the specification of SAE grade 3. The endurance limit in tension is better than that for quenched and tempered bolts.—A. M. F.

Metallurgical and Property Relationships in Stainless Steels. S. J. Rosenberg. (Product Engineering, 1949, vol. 20, Dec., pp. 81–86). The iron–carbon diagram is explained and the influence of increasing percentages of chromium is shown. Comprehensive data on the heat-treatment and properties of the straight chromium steels and of the martensitic, ferritic, and austenitic stainless steels are presented.—R. A. R.

Low-Carbon Stainless Steels Make Possible Savings in Welded Fabrication. J. B. Campbell. (Materials and Methods, 1950, vol. 31, Apr. pp. 63–66). Normal austenitic stainless steels containing 0·08 to 0·10% of carbon are susceptible to intergranular corrosion after welding. This can be remedied by annealing after welding, or by using a steel containing expensive carbide stabilizers (titanium or columbium). Quite recently, however, austenitic stainless steels having maximum carbon contents of 0·03% have been produced, which do not suffer from the disadvantage of intergranular corrosion. The American types 304, 316, and 317 have all been produced with this reduced carbon content, and whilst they are not suitable for service at temperatures above 800° F., (after welding), they do find many applications in chemical, textile, and paper plants for storage tanks. The tensile strength and hardness of these low-carbon grades are only slightly lower than for materials of regular carbon content, and their corrosion resistance is generally equal to that of the columbium-stabilized steel in the same condition, or to the corresponding regular carbon grades in the welded and annealed condition.—P. M. C.

Steels for Die-Casting Dies and Forging Dies. R. Štefec. (Hutnické Listy, 1950, vol. 5, June, Supplement No. 2, pp. 76–79). [In Czech]. The requirements to be met by steel for dies are discussed. The author gives information on the Czech steels used for die-casting and forging dies, and on the best heat-treatment. The importance of correct heat-treatment is stressed. The purpose of heat-treatment is to obtain a homogeneous sorbitic structure and to decompose any residual austenite. During the war the U.S.S.R. introduced a chromium–manganese–molybdenum steel to replace one with Ni 1·5% and Mn 1·5%. The results obtained with this relatively cheap steel were so satisfactory that it is still used and is included in the appropriate post-war Russian steel specifications.—E. G.

METALLOGRAPHY

Study of Cleavage Surfaces in Ferrite. E. P. Klier. (American Society for Metals, Oct., 1950, Preprint No. 31). The structures at cleavage surfaces in ferrite have been examined by X-ray, fractographic, and metallographic procedures. It was found that plastically strained metal exists at such surfaces in course-grained ferrite over a wide range of testing conditions. The fibres of plastically strained metal at a cleavage surface may lie in the direction of crack propagation. The fracturing process of ferrite involves cleavage along the (100) plane, and probably the (112).—E. T. L.

On the Solution Mechanism of Carbides in Austenite. V. I. Arkharov and S. T. Kiselev. (Izvestiya Akademii Nauk, S.S.S.R., 1949, Jan., No. 1, pp. 136–137). The changes in the composition of the carbides during the annealing and quenching of a low-alloy tungsten steel (C 1%, Ni 2%, Cr 4%, Si 0·24%, Mn 0·16–0·23%, W 2·5% in one heat and 1·4% in the second) have been investigated by X-ray methods. The results confirm those obtained earlier with high-alloy steels, namely, that it is mainly iron which migrates from the carbide into the austenite as each single crystal of carbide goes into solution on heating the steel above Ac_3.—R. A. R.

Spacings of Retained Austenite in Quenched White Cast Iron. W. J. Wrazej. (Nature, 1950, vol. 165, Mar. 18, pp. 447–448).

Low-angle glancing reflection X-ray photographs of quenched white cast-iron samples were taken. By means of the combined substance methods, using copper and tungsten, the lattice parameter of the retained austenite was determined. One value, $a = 3{\cdot}64$, (carbon content $1{\cdot}776\%$) is the highest yet given for iron–carbon alloys. The results demonstrate the usefulness of the combined substance method and indicate that the nature of retained austenite is determined mainly by the quenching temperature.—A. G.

Carbide Formation during the Isothermal Decomposition of Austenite in Chromium Steels. B. Yu. Mett and R. I. Entin. (Doklady Akademii Nauk S.S.S.R., 1950, vol. 72, No. 3, pp. 497–500). Carbide formation during the decomposition of the austenite in chromium steels has been studied using specimens containing 4%, 8%, and 16% of chromium. The general conclusion is that in a temperature range below the A_1 point the beginning of the decomposition of the austenite is associated with the formation of a stable carbide.—R. A. R.

Some Notes on Isothermal Transformations of Inclusions Characteristic of Ferrochromium Alloys. R. Zoja. (Metallurgia Italiana, 1950, vol. 42, Aug.–Sept., pp. 321–325). A detailed study is made of the characteristic isothermal transformations of the β constituent (as well as of the less important α constituent) namely, metallic precipitates, transparency with brown colouring, and finally the passage to green coloration. At 1300° C., however, the inclusions melt and the structure, after cooling, shows the appearance of very small chromite crystals with red reflections and chromium oxide with green reflections on a silicate background. Based on this and previous research, it would appear that 95% of inclusions in ferrochromium alloys are made up of two fundamental α and β constituents, the first with a very high percentage of SiO_2 and the second very rich in Cr_2O_3, or alternatively other constituents derived from SiO_2 and Cr_2O_3 by reduction. The author suggests that the reducing agent might be silicon or hydrogen.—M. D. J. B.

The Transformation of Austenite in 8630 Steel. R. A. Grange, J. F. Boyce, and V. G. Peck. (Metal Progress, 1950, vol. 57, May, pp. 637–642). The **S**-curve is given for 8630 steel (C 0·30%, Mn 0·80%, Si 0·29%, Ni 0·54%, Cr 0·55%, Mo 0·21%), also continuous cooling diagrams, hardness and microstructural variations along an end-quenched hardenability bar, data on the martensite range, and optical and electron micrographs.—E. T. L.

Reactions Produced by Work-Hardening and Preheating in 18/8 Steels Low in Carbon. P. Bastien and J. Dedieu. (Comptes Rendus, 1950, vol. 231, Oct. 23, pp. 862–864). Steels with compositions (*a*) C 0·035%, Cr 18·3%, Ni 10%, and (*b*) C 0·040%, Cr 17·8%, Ni 9%, Mo 0%, were both 70% work-hardened. Steel (*a*) remained austenitic whilst (*b*) contained 80% of the α-phase. Reheating of (*b*) causes at about 510° C. the formation of a fine globular precipitate of a new phase. This phase progressively redissolves towards 750–800° C. and its lattice spacing corresponds to that of the sigma phase.—A. G.

Lattice Parameters of Martensite and of Austenite. J. Mazur. (Nature, 1950, vol. 166, Nov. 11, p. 828). Values for steels containing 0·45% to 1·25% of carbon were obtained using 9-cm. and 19-cm. Debye-Scherrer cameras, with cobalt radiation to provide X-ray diffraction photos. The figures for austenite satisfy the Dannatt-Wrazej straight-line relation and confirm the presence of retained austenite in a quenched steel with 0·45% of carbon.—A. G.

Carbide Precipitation in Type 304 Stainless Steel—An Electron Microscope Study. E. M. Mahla and N. A. Nielsen. (American Society for Metals, Oct., 1950, Preprint No. 16). Studies have been made on 18/8 steel, sensitized by a solution of bromine in methanol, with an electron microscope, in an attempt to correlate the form of carbide precipitate (found to be $Cr_{23}C_6$) with corrosion. No obvious correlation was discovered. The size, form, and distribution of the carbide precipitates were studied, as affected by heat-treatment and cold reduction.—E. T. L.

Influence of Austenitizing Time and Temperature on Austenite Grain Size of Steel. O. O. Miller. (American Society for Metals, Oct., 1950, Preprint No. 15). Measurements were made of the grain size of specimens of low-carbon steels after various times and temperatures of austenitization, on cooling down to room temperature. Increase in austenitization time causes grain growth, which for fine-grained steels is retarded initially for a time increasing with decreasing austenitization temperature. It appears that grain growth can continue indefinitely. The rate of austenite grain growth is affected by the austenite grain size present, and retarded by inclusions. Isothermal growth of austenite grains does not cease when the angles of a grain approach 120°. There are 45 references.

E. T. L.

Formation of Austenite in High-Chromium Stainless Steels. C. B. Post and S. Eberly. (American Society for Metals, Oct., 1950, Preprint No. 14). Microscopical investigation shows that, contrary to general assumption, high-chromium steels (American Iron and Steel Institute type 446) can contain austenite at high temperatures, because of the presence of impurities. Rapid cooling causes retention of some austenite, which alters the expansion properties of the alloy, making it unsuitable for glass-to-metal seals, for instance. Ferrite-forming tendency relative to the potency of chromium is found to be silicon (+ 4·0), manganese (− 0·5), nickel (− 1·5), carbon (− 22), nitrogen (− 30); this enables one to calculate the equivalent chromium content; from this the chromium to be added to give 100% ferrite at a particular temperature can be calculated.—E. T. L.

Hardening of High-Chromium Steel by Sigma Phase Formation. J. J. Gilman. (American Society for Metals, Oct., 1950, Preprint No. 11). The rate of sigma formation is studied by hardness measurements and microscopy as a function of composition, initial ferrite, cold-work, annealing, rolling temperature, method of casting, comparison of cast and wrought metal, and recrystallization. Four steels had about 24% of chromium, 5% of nickel, 0·3% of carbon, and various amounts of manganese, silicon and molybdenum, and it is shown that hardening is mixed-phase hardening due to the formation of sigma. Sigma formation is stimulated by chromium, molybdenum, and silicon, and also by cold-work.—E. T. L.

Transformations in Ferritic Chromium Steels between 1100 and 1500° F. (595 and 815° C.). F. J. Shortsleeve and M. E. Nicholson. (American Society for Metals, Oct., 1950, Preprint No. 10). X-ray diffraction was used to study the ferrite/ferrite-plus-sigma phase boundary on the iron side of the iron–chromium diagram, and showed that small silicon or manganese additions shift the boundary to lower values of chromium and higher temperatures; this is the opposite to the effect of carbon, which forms cubic iron–chromium carbide. Sigma is more rapidly formed in the presence of carbides and other steelmaking elements, and forms by nucleation and growth processes.—E. T. L.

Analogies between Steels and Aluminium Bronzes. H. Laplanche. (Institute of British Foundrymen, 1950, Paper No. 977). The analogy between the thermal diagrams of the binary alloys Fe–Fe_3C and Al–Cu is discussed in detail, with reference to atomic structure, lattice dimensions and electronic concentrations. The microstructures after very slow cooling are next considered, the principal analogies being between ferrite and the α-phase of Al–Cu alloys, and between pearlite and the $\alpha + \gamma$ eutectoid of the aluminium bronzes. This is followed by consideration of as-cast structures and the effect of heat-treatment which leads to a discussion of the particular characteristics of the martensitic structure in steels and Al–Cu alloys. The whole subject is treated in considerable detail and there are 149 references.—P. C. P.

Constitution and Mechanical Properties of Zirconium–Iron Alloys. E. T. Hayes, A. H. Roberson, and W. L. O'Brien. (American Society for Metals, Oct., 1950, Preprint No. 29). A diagram developed for zirconium-rich, zirconium–iron alloys shows a eutectoid at 2·5% iron, 800° C., and a eutectic at 16% iron, 934° C. The maximum solubility of iron in β-zirconium is 5·5%, and in α-zirconium (hexagonal) less than 0·02% iron. Alloys with less than 7% iron can be worked at 850° C. Tensile data are given for the hot-rolled, quenched, drawn, and cold-worked alloys.—E. T. L.

The Ternary System Chromium–Molybdenum–Iron. J. W. Putman, R. D. Potter, and N. J. Grant. (American Society for Metals, Oct., 1950, Preprint No. 26). Chromium–iron–molybdenum alloys were induction melted and purified by vacuum melting. Thermal analysis and liquidus temperature measurements were made, and the effect of previous heat-treatment investigated. X-ray diffraction data on Fe_2Mo_3 and Fe–Mo sigma phase are also given. All ternary alloys with less than 30% iron have melting points above 1650° C. Molybdenum is shown to promote greatly the high-temperature stability of Fe–Cr sigma.—E. T. L.

CORROSION

The Corrosion Products on Zinc Anodes Used Underground. A. E. Anderson. (Corrosion, 1950, vol. 6, Apr., pp. 129–131). An examination of the corrosion products on two zinc anodes used in gypsum-bearing soil is reported. Adjacent to the zinc a porous, needle, or plate-like mass of crystals of basic zinc sulphate was found, beyond this a dense white mixture of basic sulphate and basic carbonate. A mechanism of formation of these layers is suggested, and the permeability of the basic zinc sulphate is used to explain the absence of the loss of current flow found after a time in other soils. O. H. G.

Field and Laboratory Evaluation of Petroleum-Base Rust Preventives. E. L. Walters and R. G. Larsen. (Corrosion, 1950, vol. 6, Mar., pp. 92–104). Field tests of petroleum-base rust inhibitors (both coatings and films) are described. Statistical methods are used to find the influence of atmospheric environment, composition, and application variables. The results of field and laboratory tests are compared, and the limitations of each type of method are indicated.—O. H. G.

Field Experience with Corrosion Protection of Galvanized Steel Substation Structures. S. L. Miller. (Corrosion, 1950, vol. 6, Apr., pp. 120–122). Comparative 'in service' tests over a period of several years of materials applied to galvanized steel substation structures are described. A material which gave excellent results was one compounded with a highly pigmented mixture of lead suboxide and aluminium in a vehicle of linseed oil, tung oil, and driers. The need for applying corrosion protection before the galvanizing has completely broken down is emphasized.—O. H. G.

Water Side Deterioration of Diesel Engine Cylinder Liners. F. N. Speller and F. L. LaQue. (Corrosion, 1950, vol. 6, July, pp. 209–215). Methods of extending the useful life of cast-iron liners used in water cooling diesel engines are discussed. Failure may be due to (1) 'Ordinary' corrosion (important factors being dissimilar metals, concentration cells at juncture of liners with engine block, variable velocities and temperatures, composition of liner and cooling water); and (2) occasional rapid local pitting, apparently of dynamic origin. 'Ordinary' corrosion can be controlled by using chromate or other water-soluble inhibitors in soft water low in organic matter. The 'dynamic' pitting is illustrated and discussed in detail. It appears to be associated with the high frequency 'cavitation' effect found in hydraulic systems. High chromate concentrations (2000–4000 p.p.m.) are beneficial, but the final solution awaits further research and probably the application of damping principles in design. O. H. G.

Cathodic Protection of Fourteen Offshore Drilling Platforms. E. P. Doremus and G. L. Doremus. (Corrosion, 1950, vol. 6, July, pp. 216–224). Over 500,000 sq. ft. of submerged bare steel surfaces on 14 drilling platforms and four accompanying drilling barges in the Gulf of Mexico have been placed under cathodic protection during the past 15 months. Present practice is to use a high current density of short duration furnished by magnesium ribbon (Galvo-line) to deposit a calcareous coating on the surfaces to be protected. This polarization treatment effectively reduces current requirements for protection to a value approaching 3 milliamp./sq. ft., and therefore a relatively small 'permanent' installation of 51-lb. magnesium anodes serves to maintain both the coating and protective potentials upon dissolution of the Galvo-line. In general, a sufficient number of anodes is installed to provide protective potentials of — 0·78 V. min., referred to a saturated calomel electrode adjacent to the surface being tested, with anode outputs uniformly adjusted to provide a life of two to three years for the protective system. Methods of installing the magnesium anodes and Galvo-line are discussed and illustrated. Current and potential data obtained during the course of a typical installation are presented, and experiences and results obtained during installations on several different types of structure are discussed. In an effort to obtain on-site data showing the differences in corrosion rates for protected and unprotected steel pilings in the splash, tidal, and sub-tidal zones, corrosion test racks have been mounted on one cathodically protected platform off the Louisiana coast.—O. H. G.

Oil Can Control Wear. R. E. Jeffrey, jun., and J. M. Plantfeber. (Corrosion, 1950, vol. 6, Apr., pp. 115–119). The use of lubricating oil to control corrosion of cylinder walls and rings of diesel engines is discussed. A new 'Special Oil' is described which has much reduced cylinder wear in certain stationary pumping and drilling units, marine generator sets, and in a marine propulsion unit operating under intermittent high-load conditions.—O. H. G.

Some Aspects of the Corrosion of Tin Plate by Prunes. V. W. Vaurio. (Corrosion, 1950, vol. 6, Aug., pp. 260–267). The mechanism of corrosion of tinplate in cans has been investigated by the prune pack method. Evidence is presented which indicates that, in prunes at least, tin corrodes at a constant rate without the evolution of measurable quantities of hydrogen. Hydrogen evolution in canned prunes is related directly to the solution of the iron of the steel base. Tests indicate that porosity of the tin coating is not an important factor in the corrosion of plain (unlacquered) cans by prunes, owing to cathodic protection of the steel base by the tin. Increased tin coating weight, up to at least 1½ lb. per base box, is shown to result in increased pack life. O. H. G.

The Influence of Stress on Corrosion. J. J. Harwood. (Corrosion, 1950, vol. 6, Aug., pp. 249–259; Sept., pp. 290–307). The literature on the effects of stress on the internal structure and energy characteristics of metals is reviewed. There are 81 references.—R. A. R.

Caustic Danger Zone. A. A. Berk and W. F. Waldeck. (Chemical Engineering, 1950, vol. 57, June, pp. 235–238). Laboratory tests on strip specimens of cold-rolled 0·20% carbon steel, bent under strain, showed that intercrystalline cracks developed when they were immersed in 15–43% sodium hydroxide solution above 180° F. Outside this zone, cracking did not occur.—T. E. D.

The Choice and Interpretation of Corrosion Tests. G. T. Colegate. (Sheet Metal Industries, 1950, vol. 27, Mar., pp. 259–266). The author discusses the factors involved in choosing tests which will give reasonably reliable information that can be used in practice to predict the probable life or performance of a metal under service conditions. Completely irrelevant and misleading results are obtained when the test conditions bear no relationship to the actual conditions of service. The similarity between test conditions and service, although difficult to attain, should always be aimed at. With this object in mind, the following types of test are discussed: Total immersion in liquids, atmospheric exposure, galvanic corrosion in liquids, and the salt-spray test.—P. M. C.

Nature and Causes of Corrosion of Metals Explained on the Basis of the Electrochemical Theory of Corrosion. F. Müller. (Technische Rundschau, 1950, vol. 42, Feb. 17, pp. 1–3; Feb. 24, pp. 2–3; Mar. 3, pp. 3–4). The author concludes that the progress of corrosion processes cannot be predicted on the basis of calculation from the electrical data applicable to the stationary state, since it is strongly influenced by dynamic conditions. Secondary corrosion products can completely change the characteristics of primary corrosion. The importance of inhibitors, a good surface quality, the use of suitable alloying elements and galvanically or mechanically deposited protective coating is emphasized. Attention is also drawn to the importance of correct design of metallic structures to prevent accumulation of dust and residues of corrosive fluids.—E. G.

Observations on Corrosion of Ferrous Metals. G. D. Lain. (Regional Technical Meetings of American Iron and Steel Institute, 1949, pp. 102–114). The author briefly discusses the mechanism of atmospheric, bacterial, chemical, and high-temperature oxidation, soil, stray current electrolysis, and underwater types of corrosion of steel, and indicates the methods of preventing corrosion. The corrosion of galvanized steel pipes by domestic waters is considered and special attention paid to the question of a reversal in potential sometimes encountered in the zinc/steel couple. A study of the available data shows that the composition of the water is an important factor affecting this reversal, and the effects of bicarbonate, sulphate, chloride, and nitrate concentrations are evaluated. G. F.

A Survey of the Application and Performance of Temporary Rust Preventives. G. T. Dunkley. (Sheet Metal Industries, 1950, vol. 27, July, pp. 599–604, 606). This is a descriptive survey of the various types of preventive, their advantages and disadvantages, and precautions to be taken in use. The author considers these materials under three headings as follows: (1) Hard film compounds, which may be divided into

those formed by the evaporation of a solvent, and those which are applied hot and form hard strippable coatings. The former are based on bitumen or resins plus lanolin, and the latter on ethyl cellulose plus oils, resins, and plasticizers (2) Soft film compounds, such as white lead/tallow mixtures, petroleum jelly plus beeswax or lanolin, lubricating oils plus lime soap, and where rubber is present, castor-oil-base greases. (3) Oil film compounds which are ordinary lubricating oils to which have been added rust inhibitors. Vapour-phase inhibitors are becoming increasingly popular for protecting delicate mechanisms like clocks.—P. M. C.

Corrosion- and Acid-Resisting Cast Steel. F. Harms. (Technische Rundschau, 1950, vol. 42, July 7, pp. 1–3). The influence of various alloying elements on the corrosion properties of steel are described and the general aspects to be considered in the selection of a steel suitable for a particular task are discussed. Data on the strength and other physical properties, on the heat-treatment, grain structure, and welding properties of German corrosion-resisting steels are given. E. G.

Corrosion Protection of Stored Plant and Machinery: Use of Fluids, Oils and Compounds at Sites of the Steel Company of Wales Limited. A. E. McAulay. (Iron and Coal Trades Review, 1950, vol. 161, July 28, pp. 187–188, 190). The effectiveness of Shell 'Ensis' protective fluids, oils and compounds, used to prevent corrosion of stored plant and machinery during the construction of the new Abbey Works of the Steel Company of Wales, Ltd., is discussed. The nature of the protectives and the methods of application and removal are briefly described.—G. F.

Corrosion Phenomena in High-Pressure Steam Generators for Ships. (Zeitschrift des Vereines deutscher Ingenieure, 1950, vol. 92, July 11, pp. 560–561). Corrosion is principally due to air in feed water and contamination with sea water. Investigations of installations in use since the 1930's have shown that corrosion can be suppressed by strict control of the *p*H value of the feed water and a regular dosage of caustic soda and trisodium phosphate. A relation was established between steam capacity and maximum alkalinity of the water, which is applicable to both natural and forced circulation boilers of various designs.—J. G. W.

Corrosion Fatigue As a Manifestation of Intra Crystalline Corrosion. F. Lihl. (Metall, 1950, vol. 4, Apr., pp. 130–132). The author points out that the fatigue resistance of pure metals and single-phase alloys is practically unaffected by corrosion and that whereas the ordinary fatigue strength of steel increases with its tensile strength, the corrosion fatigue strength is practically independent of it. At the same time neither pure metals, nor single phase alloys, nor steel tested in a corrosive medium, exhibit a clear fatigue limit, the *S*–*N* curve never becoming asymptotic to the *N*-axis. The author explains this and similar phenomena on the hypothesis that corrosion fatigue is a manifestation of intra-crystalline corrosion. He postulates that the segregation of impurities along mosaic block boundaries is a source of strength, and that this segregation is in the form of a fine dispersion which persists even after long heat-treatment which is sufficient to cause coagulation of similar segregations along grain boundaries. This intra-crystalline network of impurities is open to rapid attack by corrosive media leading to a weakening of the grains and to minute intracrystalline cracks. The author then elaborates the argument for the case of a simple fatigue test on a partly corroded specimen, of a corrosion fatigue test, for the corrosion fatigue strength of annealed and hardened steels, for the case of alternating tension and alternating compression in corrosion fatigue, and for the connection between cycle frequency and corrosion fatigue, and he demonstrates that his hypothesis leads to conclusions in accord with observations.—J. G. W.

Stress Corrosion Cracking of Mild Steel. D. Cubicciotti and W. Boyer. (Welding Journal, 1950, vol. 29, Mar., pp. 140s–145s). Mild steel wire was stressed and then subjected to a corrosive attack by a NH_4NO_3 solution at 100° C. The effect of temperature of heat-treatment of the wire was investigated using air, nitrogen, or hydrogen. Some heat-treatment was necessary to cause stress corrosion since no cracking was observed if untreated. The gaseous atmosphere used had little effect on breaking time. The heat-treatment may have been effective only in allowing some constituent to diffuse outwards or inwards. In order to produce stress corrosion it was necessary to have nitrate present with an acidic cation. Rate of change of breaking time with temperature was found to be different for ammonium and magnesium nitrate solutions.—U. E.

The Effect of Previous Oxidation on the Corrosion of Cast Irons in Liquid Aluminium and Light Alloys Containing Silicon. P. Bastien and P. Azou. (Fonderie, 1950, July, pp. 2111–2120). Previous work on the resistance to attack by dissolution of some cast irons in molten aluminium, Alpax (Silumin), and hyper-silicon showed that iron containing 32% chromium had very low corrosion resistance whilst the light alloys showed up well. In that work, no previous oxidation was given. It was agreed to study the effect of previous preparation of the surface by heating to 850° C. in air. A 32% Cr iron, a grey pearlitic iron, a malleable iron, and a rolled mild steel were used. The corrosive media were a double-refined aluminium, Alpax (Si 11·57%, Mg 0·98%, Cu trace, Fe 0·7%) and a hyper-silicon (Si 15·92%, Mg 0·77%, Cu 0·16%, Fe 0·8%) at 850° C. The degree of corrosion was determined by loss in weight. Details are given for the various metals in each medium and for varying periods of previous oxidation treatment. The value of a protective oxide layer in resisting the active corrosive media studied, is clearly shown.—R. S.

Steel, Heat and Water: Localized Formation of Magnetic Iron Oxide in Power Boilers. H. M. Rivers and W. M. Sonnett. (Blast Furnace and Steel Plant, 1950, vol. 38, June, pp. 694–696, 720, 722, 723). Several types of corrosive attack in power boilers are discussed. The main types considered are: Simple corrosion by high concentration of caustic, corrosion by caustic in the concentrating film, attack under adherent deposits, hydrogen damage, gouging caused by steam blanketing, and corrosion fatigue.—J. P. S.

Notes on the Anticorrosive Action of Emulsified Oils. A. Ferri. (Metallurgia Italiana, 1950, vol. 42, July, pp. 261–267). The author determines, by means of electrochemical methods, that oils mixed with water are anodic and therefore dangerous as they can start local corrosion. Other substances in oils are also studied in relation to their action on metals. Amongst these, potassium bichromate has proved to be the most suitable complementary substance for oils as it is strongly cathodic.—M. D. J. B.

ANALYSIS

Precision of Spectrographic Analyses of Steel. P. R. Irish. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 110–117). The Bethlehem Steel Company uses spectrographic analysis to control the operating of four electric and 32 open-hearth furnaces, and the laboratory makes about 7000 determinations per week with a staff of five men on each shift. The following factors affecting the precision of the results are discussed: (1) The computing method; (2) density difference of line-pair; (3) wavelength separation of line-pairs; (4) difference in excitation of line-pairs; and (5) the use of standard samples.—R. A. R.

Routine Spectrochemical Analysis in the Ford Motor Company. G. A. Nahstoll. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 117–118). Brief descriptions of the spectrographic analysis laboratories of the Ford Motor Company are given. Each laboratory has equipment for a 35,000-V. spark and a 2000-V. arc. The foundry has a Bausch and Lomb quartz spectrograph and uses a 4 × 11½-in. photographic plate. The steel laboratory has a Hilger spectrograph (range: 2100 to 3600 Å.) and uses 35-mm. film. There is also a mobile laboratory fitted with spectroscope and spot-testing and physical testing equipment; this is used for analysing scrap from trucks and lorries, as well as for sorting steel which may have got mixed.—R. A. R.

Use of the Spectrograph in the Analysis of Special Steels. M. L. Windle and W. H. Magrun. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 119–122). The precision of the spectrographic methods applied by the Simonds Saw and Steel Company to control the making of low-alloy tool steel, high-speed steel, and stainless, magnetic, and heat-resisting steels is discussed. Precision tests for three different types of spectrographic equipment were made. The deviations indicated that errors would never be more than 0·36% for tungsten, 0·18% for molybdenum, 0·16% for nickel, and 0·24% for chromium.—R. A. R.

XUM

Spectrographic Analysis of High-Alloy Steels. D. G. Schoffstall. (American Insitute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 122–124). The Carpenter Steel Company has been making spectrographic analyses for the last five years and now operates a research and a production control laboratory each equipped with a Jarell-Ash spectrograph with a grating in a Wadsworth mounting. The method is particularly useful to control the manganese and silicon in stainless steels by taking samples 15–20 min. before tapping without delaying tapping. These analyses are made with third-order spectra without interference from chromium. The cost per determination is considerably less with the spectrograph than with wet methods.—R. A. R.

Spectrographic Analysis by Copperweld. A. C. Hale. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 124–125). The Copperweld Steel Company now uses a Bausch and Lomb large Littrow spectrograph. Two men per shift make control analyses for seven electric furnaces producing up to 50 heats in 24 hr. A Baird Associates direct-reading spectrometer has recently been installed and is now being calibrated and tested, the elements and ranges in which they will be determined are: Mn 0·05–2·30%, Cr 0·02–2·00%, Ni 0·02–4·00%, Mo 0·01–1·00%, Cu 0·02–1·00%, Si 0·003–2·20%, Al 0·005–1·50%, W 0·01–2·00%, V 0·01–0·50%, Sn 0·01–0·25%, and Pb 0·01–0·25%.

R. A. R.

Spectrographic Analysis at the American Cast Iron Pipe Company. W. R. Kennedy. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, pp. 125–126). The American Cast Iron Pipe Company has for nine years used the spectrograph for control analysis when making alloy steels, stainless steels, and alloy cast iron as well as for oxide analysis of acid and basic slag. Rod samples are used directly in the spark gap, while flat samples and briquettes are sparked with a pure carbon counter electrode. Two men take about 10 min. for a complete analysis for silicon, manganese, chromium, copper, and aluminium.—R. A. R.

Spectroscopy at Canton Division, Republic Steel Corporation. E. O. Waltz. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference Proceedings, Dec., 1949, vol. 7, p. 127). A brief account is given of the service rendered by the spectrographic laboratory at the Canton Division of the Republic Steel Corporation. Its performance includes: (1) Servicing up to six open-hearth and twelve electric furnaces; (2) it has consistently shown a comparative accuracy of less than 3% of the element content in the steels analysed; (3) more than 300 samples per day have been made at an average cost of 50 cents per sample; and (4) determinations of tin, aluminium, tungsten, and columbium in stainless types.—R. A. R.

Direct Reading Quantometer Analysis of Phosphorus in Steels. M. F. Hasler and F. Barley, jun. (Applied Research Laboratories, Glendale, June, 1949). Detailed study has shown that a suitable interrupted arc discharge for low-percentage residual elements in steel is obtained with the Multisource for capacity 40 microfarads, inductance 400 microhenries, resistance 50 ohms, and ignitor resistance 5 ohms. The same discharge is most suitable for determining phosphorus using the Quantometer to permit direct reading. The line P 2149·11 is employed in spite of some interference by the line Cu 2148·97; a correction is made for this interference by making copper and phosphorus determinations simultaneously and calibrating the copper scale in terms of a phosphorus correction. With a sample containing 0·05% Cu, 20 determinations gave 0·042% ± 0·003%. The technique is described.—R. A. R.

The Analysis of Cast and Malleable Irons with the Spectrograph Quantometer Adapter. M. F. Hasler. (Applied Research Laboratories, Glendale, Mar. 7, 1949). A direct reading method for the determination of silicon, manganese, and chromium in cast iron has been developed. It utilizes chilled cast block samples excited by the point to plane technique. Samples can be analysed at the rate of one every 2 min. This time includes grinding the sample, sparking, and recording the results on a strip chart. The accuracy obtainable is superior to ordinary spectrographic analysis.—R. A. R.

The Bragg Laboratory. (Metal Industry, 1950, vol. 76, June 23, pp. 483–485; June 30, pp. 499–501). These laboratories, also referred to as the Naval Ordnance Inspection Dept., are situated in Sheffield, and are mainly concerned with the chemical and metallurgical inspection of metals and non-metals on behalf of the Admiralty. The article describes the activities of the various sections, giving an account of the apparatus and equipment available. Much useful original research has been carried out on new methods of chemical analysis, using the Spekker photo-electric absorptiometer and the spectrograph.—P. M. C.

Bibliographic Focus on the Chemical Analysis of Materials of Interest in Ferrous Metallurgy. M. Jean. (Chimie Analytique, 1950, vol. 32, June, pp. 133–138; July, pp. 162–167; Aug., pp. 179–183; Sept., pp. 213–217). The publications summarized here concern the analysis of steels and iron alloys. They are chiefly from 1944 onwards, but earlier papers of importance are not neglected. The elements whose analyses are included are as follows: Carbon, silicon, manganese, sulphur, and phosphorus; copper, nickel, chromium, molybdenum, tungsten, cobalt, and arsenic; titanium, vanadium, aluminium, tin, lead, tantalum, niobium, boron, and those elements more rarely added, zinc, cadmium, germanium, cerium, selenium, calcium, magnesium, antimony, beryllium, and bismuth; and the gaseous elements, nitrogen, oxygen, and hydrogen. There are 439 references.—T. E. D.

Statistical Methods Applied to Analytical Chemistry. M. Vignau. (Chimie Analytique, 1950, vol. 32, Jan., pp. 7–13; Feb., pp. 35–41; Apr., pp. 85–89; May, pp. 109–114; July, pp. 156–161; Aug., pp. 185–189). In this mathematical paper, many worked examples of the application of statistical methods to analytical chemistry are given.—T. E. D.

A Note on Precision in Metallurgical Analysis. E. H. S. van Someren. (Metallurgia, 1950, vol. 42, June, p. 52). A plot is given of the coefficient of variation of a number of results of ferrous analyses against the mean content of the element analysed in the iron. The author has drawn a 'best straight line' through them, which shows that the coefficient of variation rises steeply with decreasing 'mean content' of the material being analysed. The author invites further information so that the whole matter may be dealt with on a satisfactory statistical basis.—J. J.

A Review of Methods of Determining Carbon in Steel. R. L. Wilson. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 161–170). A brief review of combustion and magnetic methods for determining carbon in steel is presented, and the possibility of obtaining accurate results more quickly is examined, in view of the introduction of the direct-reading spectrometer which is capable of giving results for as many as eight alloying elements within 6 min. from sampling. Magnetic methods, such as the 'carbometer' and 'carbanalyser,' are known to match the spectrometer in speed and to give reliable results for carbon steel, and their possible application to alloy steels is considered.—G. F.

Chemical Analysis of Metals Without Taking Drillings of the Material to be Analysed. V. L. Zolotavin. (Elektricheskie Stancii, 1950, Mar., p. 2). [In Russian]. A chemical method of determining the silicon and manganese contents of a steel boiler plate without removing chips or drillings is described.—E. G.

The Use of the Spectroscope in the Steel Industry. E. O. Waltz. (American Iron and Steel Institute: Blast Furnace and Steel Plant, 1950, vol. 38, June, pp. 662–665). The author points out the saving in time and labour gained by using the spectrograph for analysing steel samples taken throughout the melting, refining, and finishing periods of manufacture. In a melting shop consisting of five arc furnaces the author estimates a possible saving of $52,000 per year in furnace time. The author mentions the recent introduction of direct-reading spectrographs which reduce the analysing time of a steel sample to approximately 6 min.

J. P. S.

Home-Made Apparatus for Spectrographic Analysis. F. Leutwein. (Die Technik, 1950, vol. 5, May, pp. 238–242). Owing to post-war difficulties in the East German instrument industry, the Mineralogical Institute of the Freiberg Mining Academy had to fall back on its own resources in building up its spectrochemical laboratory. The author describes two spectrographs, one with a quartz the other with a glass prism, a spectrometer, portable spectroscope, electrode holder, film projector, and photometer—all designed and built in the institute. The design follows conventional principles but small innovations, such as a motor-driven traverse

on the projector, have been incorporated for the convenience of the investigator.—J. G. W.

Direct Reading and Spectrography with One Instrument. P. Coheur and A. Hans. (Applied Research Laboratories, Glendale, 1950). By utilizing simultaneously the first order of a large grating spectrograph for direct-reading analysis and the second order for spectrographic analysis, a direct comparison between electronic and photographic recording is possible. This has been done for a wide variety of steel samples with measurements on manganese, silicon, and chromium contents. The real superiority of direct reading over spectrographic analysis is demonstrated by typical data obtained by the two methods. Errors due to metallurgical effects, and means of reducing them are discussed. Standard deviations as low as 0·6% of the manganese content are obtained on repeat analysis by employing direct reading and the metallurgical practices described.—R. A. R.

Contribution of the Source Unit to Variability in Spectrographic Analysis. (Journal of The Iron and Steel Institute, 1950, vol. 166, Dec., pp. 325–328). This is a report by the Spectrographic Analysis Sub-Committee of the Methods of Analysis Committee of the British Iron and Steel Research Association. A more comprehensive assessment of source behaviour, based on the technique outlined in an earlier paper, has confirmed that about 20–50% of the total error in spectrographic ferrous analysis, using photographic recording, can be traced to source contribution. Some of the factors affecting this contribution and the possibilities of improved source performance are considered.

Account of the Work of l'Institut d'Astrophysique de l'Université de Liège. P. Swings. (Centre National de Recherches Métallurgiques, Conference on Spectrum Analyses, Dec. 22, 1949: Revue Universelle des Mines, 1950, Series 9, vol. 6, Mar., pp. 74–79). Details are given of some of the work of the above research laboratories which is of interest to metallurgists. This includes the construction and use of a large diffraction grating, a King vacuum furnace for the determination of occluded gases, the hollow-cathode method of gaseous spectroscopic analysis, and a spectrometer for use with sources of very low intensity.—B. G. B.

What One Can Expect from the Application of Spectrographic Methods to Metallurgy. A. Hans and L. Lacomble. (Revue Universelle des Mines, 1950, Series 9, vol. 6, Aug., pp. 230–236). Details are given of the rapid determination of manganese, silicon, nickel, chromium, and molybdenum in steel. Two methods have been developed. The first involves exposure and development of a photographic film and subsequent photometric study. Using this method the time for determination of the first element is 6 min. with 25 sec. for each successive element. The second is the 'direct' method employing a Geiger tube for the direct determination of the strength of the spectral lines; it enables determination of the first element to be completed in 50 sec. and 5 sec. for each successive element. A report is also given of works carried out on the application of these techniques to slag analysis.

B. G. B.

Revue of the Work of Gillis, Eeckhout, Mathien, Hans, and Breckpot. P. Coheur. (Centre National de Recherches Métallurgiques, Conference on Spectrum Analysis, Dec. 22, 1949: Revue Universelle des Mines, 1950, Series 9, vol. 6, Mar., pp. 71–74). Work has been carried out on the application of spectroscopic techniques to: (1) Analysis of slags and steels, (2) determination of residual elements in steels, (3) direct analysis of steels and zincs, (4) rapid determination of phosphorus (in 30 sec.) and (5) direct analysis of occluded gases. Details are given of the results obtained.—B. G. B.

Colorimetric Determination of Silicon in Malleable Cast Iron. L. Kučera. (Hutnické Listy, 1950, vol. 5, June, Supplement No. 2, pp. 102–107). [In Czech]. The problem of rapidly determining elements in the melt during the production of malleable cast iron, and previous work on this subject, are briefly reviewed. Research work in the laboratories of the Českomoravska Kolben Daněk is reported. On the basis of over 4000 tests a practical method for silicon in the range 0·05–15% was developed. Detailed instructions are given for malleable iron and the total time required is 19 min. The accuracy is very high. The colorimetric method is also being applied to the determination of phosphorus, titanium, vanadium, copper, nickel, chromium, cobalt, tungsten, and the combined carbon. Two photo-electric colorimeters are described.—E. G.

Determination of Impurities in Inert Gases. R. E. Bowman and C. B. Hartley. (Welding Journal, 1950, vol. 29, May, pp. 258s–264s). Equipment and techniques were developed for determining the total impurities in argon and helium used in arc welding. The method is based on the fact that molten lithium absorbs nitrogen, oxygen, and water vapour. The gas sample was admitted into a constant-volume apparatus where the impurities were removed by the molten lithium. The change in pressure at a standard temperature produced by the removal of the impurities was used to determine the purity of the gas. Since the total impurities in argon for welding were less than 0·2%, a special apparatus was constructed to minimize errors due to small changes in atmospheric pressure and temperature. The apparatus was satisfactory. The maximum error in the determinations was about 0·01% of the total volume. The impurities in the samples of argon that were tested amounted to about 0·14% of the total volume.—U. E.

Polarographic Determination of Molybdenum in Steel. M. Stepien. (Prace Badawcze Glownego Instytutu Metalurgii i Odlewnictwa, 1950, No. 2, pp. 89–91). [In Polish]. A new method of polarographic determination of molybdenum in steel has been worked out. A sample is dissolved in a mixture of hydrochloric and nitric acids (for stainless steel sulphuric acid is used). Molybdenum sulphide is precipitated by passing a stream of hydrogen sulphide through the solution, and it is then oxidized to sulphomolybdate with bromine. After coagulation, sulphuric acid (1 : 1) is added and polarographic determination takes place at potential $E = -0{\cdot}25$ V. The product of reduction is unknown. The percentage of molybdenum can be calculated in two ways: (1) Indirectly by comparing with the standard curve or (2) directly by using a formula for determining the value of constant 'I' for the diffusion current. In the case of molybdenum content in the 0·1–0·5% range, the error does not exceed ± 10%. The analysis takes about 6 hr.—V. G.

Quantometer Analysis of Phosphorus in Steels. (Spectrographer's News Letter, 1950, vol. 3, May, pp. 1–3). A method of using the production control quantometer for determining phosphorus in steels when copper is also present is described. Satisfactory results can be obtained with copper contents up to four times the phosphorus content.—R. A. R.

The Photometric Determination of Phosphorus in Low-Alloy Steels. A. Bacon. (Analyst, 1950, vol. 75, June, pp. 321–335). The effect of residual ferric iron on the reduction of phosphomolybdate, both by stannous chloride and by ferrous sulphate, has been studied in order to improve the accuracy of the photometric determination of phosphorus. The production of ferrous sulphate by the reduction of ferric iron with sulphurous acid is described, and some details of fundamental reagent concentrations are given. From these results a method is presented, which, if carefully controlled, gives results reproducible to ± 0·001% of phosphorus. These results are slightly lower than referee gravimetric results, and calibration by the referee method is recommended.—J. B. B.

Nephelometric Determination of the Oxygen Content of Liquid Steel. M. Šicha. (Hutnické Listy, 1950, vol. 5, June, pp. 234–239). [In Czech]. The nephelometric method of determining oxygen in liquid steel has been applied to 55 samples from open-hearth and electric furnaces to determine whether it is suitable as a rapid method. Using samples of 2·5 and 4 g. their oxygen content was between 0·002 and 0·076%. Determinations were carried out with a Spekker photometer. The method was found suitable for the rapid analysis of casting-pit samples, the time required being 12–15 min. Detailed instructions on procedure are included. A modified Herty method of sampling liquid steel is also discussed.—E. G.

Rapid Qualitative Analysis of Bentonite. A. Bichler. (Hutnické Listy, 1950, vol. 5, June, p. 248). [In Czech]. The research laboratories of the Třinec ironworks developed a rapid method of qualitative analysis for bentonite. The montmorillonite particles are separated from the gel by centrifugal force. Five to 0·5 g. of bentonite per 1000 c.c. of water are used and the speed is 2400 r.p.m. Results are given for various Czech and foreign bentonites.—E. G.

Rapid Analysis of Refractory Bricks Containing Chromium, Magnesite, Radex, and Chromium Oxide. S. Sajó. (Bányászati es Kohászati Lapok, 1950, vol. 5, July, pp. 427–428). [In Hungarian]. The author describes a rapid method of analysing chromium magnesite refractory bricks for the

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determination of Cr_2O_3, Fe_2O_3, CaO, MgO, Al_2O_3, and MnO. A complete analysis takes about 4 hr. and the accuracy is the same as that of standard methods requiring 4 to 5 days.—E. G.

Rapid Analysis of Open-Hearth and Blast-Furnace Slags. I. Sajó. (Iron and Steel Institute, 1950, Translation Series No. 410). This is an English translation of a paper which appeared in Bányászati és Kohászati Lapok, 1950, vol. 5, Jan., pp. 68–70 (*see* Journ. I. and S.I., 1950, vol. 165, June, p. 253).

HISTORICAL

The Influence of Osmond on the Development of the Physical Metallurgy of Steel. G. B. Willey. (Sheet Metal Industries, 1950, vol. 27, Mar., pp. 211–217, 220; Apr., pp. 311–322). This article is an exhaustive review of the development of the physical metallurgy of steel, from about 1880 onwards. It seems clear that the subject, as a systematic doctrine, is due chiefly to M. Floris Osmond, born in 1849. Immediately after Le Chatelier had constructed an accurate pyrometer, Osmond applied it to determine the behaviour of iron and steel on slowly heating and cooling. He demonstrated the existence of change points, concluded that iron existed in different allotropic forms, and took up Sorby's application of the microscope. He quickly arrived at a coherent though not at first exact explanation of the various heat-treatment processes, and he studied and named several of the main microstructures. His chief mistake was his conclusion that β-iron was hard and the cause of hardness in quenched steels. There are 43 references.—P. M. C.

The Iron Industry of the Oberpfalz in the Middle Ages and Early Modern Times. F. M. Ress. (Archiv für das Eisenhüttenwesen, 1950, vol. 21, July–Aug., pp. 205–215). The growth and flourishing period of the iron industry in this region are outlined. Ore, wood, and water formed the basis on which it was built and their importance is discussed in connection with the various production methods (direct, blast-furnace, and sintering) and with the working-up into sheets. The production techniques, the social structure, and organization of the mining and metallurgical industries of the Oberpfalz afford a completely new picture of a vanished major industry which in the later middle ages and early modern times was of great importance both near and far.—J. P.

The Centenary of the Coke Blast-Furnace in the Ruhr. M. Paschke. (Stahl und Eisen, 1950, vol. 70, Aug. 17, pp. 741–742). The development of the coke blast-furnace, from the reputed success of Dud Dudley in England to the first blowing-in at Le Creusot in France, is briefly reviewed. The introduction of the coke furnace at the Friedrichs-Wilhelms works at Mülheim and the pioneer work of Julius Römheld are described.—J. P.

ECONOMICS AND STATISTICS

The Effect of Raw Materials on Steelmaking. K. L. Fetters, E. G. Hill, H. C. Smith, and C. H. Herty, jun. (Regional Technical Meetings of American Iron and Steel Institute, 1948, pp. 47–56). The steady depletion of high-quality raw materials used in the American iron and steel industry and the resulting problems in steelmaking practice are discussed. The probable future trends in the industry caused by the changes in raw materials are indicated.—G. F.

The Standardization and Simplification of Steel Products. L. H. Winkler and J. G. Morrow. (Regional Meetings of American Iron and Steel Institute, 1948, pp. 15–33). The history of the standardization of steel grades and products is traced from the formation of the various standardizing organizations to the present-day level. The benefits derived from this, and from the simplification or concentration of production on the most important sizes or items of a product, are discussed.—G. F.

Standardization and Metallurgy. J. G. Haenel. (Mineração e Metalurgia, 1950, vol. 15, May–June, pp. 27–28). [In Portuguese]. Before the war the Brazilian Association of Standardization had only three standards relating to metals. The necessary development of the 'co-ordination of economic mobilization' of resources is traced and the advantages of standardization are outlined. Large undertakings like Volta Redonda and the Cia. Siderurgica Belgo-Mineira entered into new phases of production during the war. A list of some 26 subjects urgently needing standardization is given.—R. S.

The Fundamental Principles of Mass Production. J. F. Kayser. (Sheet Metal Industries, 1950, vol. 27, June, pp. 527–528, 530). The strict co-ordination of processes, and steady flow of uniform raw material, are both necessary for successful and economical mass production, irrespective of the class of product. The author discusses uniformity at some length, and illustrates his views by reference to a simplified and hypothetical procedure for the manufacture of hacksaw blades from cold-rolled strip.—P. M. C.

World Steel Market in 1949. M. Grabania. (Hutnik, 1950, vol. 17, May–June, pp. 124–131). [In Polish]. Some data about world iron and steel production in 1949 are given. No absolute values of production in the U.S.S.R. are stated, but figures are quoted as percentages of 1948 production which is taken as 100.—V. G.

The French Iron and Steel Industry. (Australian Foundry Trade Journal, 1950, vol. 1, July, pp. 8–9). France now ranks fourth amongst the world's steel producers, the steel output amounting to an annual rate of nearly 11 million metric tons. Of this 60% is produced by the improved basic-Bessemer process, 33% by the open-hearth, and 5% by the electric arc. The principal items manufactured are merchant bars, structural shapes, plates and sheets, and rail and track materials. The increase in production has led to a virtual abandonment of all controls. The inclusion of the Saar in the industry has greatly improved the supply of metallurgical fuels, and France has extensive reserves of iron ore. It is hoped to increase the rate of production by 1952–53 to a total of 14,300,000 metric tons annually.—J. E. W.

The Development of the Metallurgical Industry of Luxemburg. M. Steffes. (Revue Technique Luxembourgeoise, 1950, vol. 42, Jan.–Mar., pp. 3–15). The situation of the major metallurgical centres in Luxemburg is shown. The results obtained by integration of four steelworks in the Esch basin are reported together with an account of recent process modifications, new installations, and modernization of the ore mines.—B. G. B.

Present-Day Problems of West German Iron Economy. M. C. Müller. (Stahl und Eisen, 1950, vol. 70, June 22, pp. 537–541). The countries of Europe are engaged in expanding and modernizing their steel industries whilst West Germany is still subjected to various restrictions and controls imposed by the occupying authorities. Economic planning is not possible except on an international scale and such planning should take into account German production. Nevertheless, unless the West German iron and steel industry is allowed to produce to a much higher level, maximum use cannot be made of this integration. The problems which will face Europe if the predicted surplus of 8,000,000 tons of steel in 1953 is realized are discussed with respect to international agreements, particularly the Schumann plan.—J. P.

The Economic and Technical Development of the West German Machine Industry since 1945. E. Schlobach. (Stahl und Eisen, 1950, vol. 70, Apr. 27, pp. 349–358). After reviewing the pre-war distribution of machine manufacture in Germany, the effects of zoning and of the regulations of the occupying authorities upon the economic development in the western zone are described. The yearly production and export of machines, in terms of quantity, value, and type, are compared with statistics from West Germany in 1936. The latest improvements in machine construction are briefly described, with particular reference to rolling-mill equipment, machine tools, woodworking, building, agricultural, textile, lifting, and conveyor equipment.—J. P.

The Iron and Steel Industry in the Russian Zone of Germany. J. Mayer. (Hutnické Listy, 1950, vol. 5, June, p. 250). [In Czech]. Most of the iron and steel works in the Soviet zone of Germany were dismantled after the war. Reconstruction was started in 1947, and in 1949 five plants were rebuilt. Pig iron is produced solely by Maximilianshütte where ore from Schmiedefeld-Kamsdorf, containing 23–25% of iron is smelted in four blast-furnaces. The rolling mills at these works produce rails and angles; the productive capacity is 173,000 tons/annum. Hennigsdorf steelworks can produce 120,000 to 150,000 tons per/annum. A blast-furnace at Riese to produce 260,000 tons per/annum has recently been blown in. The pig-iron production in 1950 is expected to be 360,000 tons and that of ingots 875,000 tons. Some works still operate at a loss and the Maxmillianshütte, and the Hennigsdorf and Riese steelworks have to rely on state subsidies.—E. G.

Statistical Survey of Sweden's Mining and Metallurgical Industry. (Jernkontorets Annaler, 1950, vol. 134, No. 2, pp. 85–96). [In Swedish]. For the period 1911 to 1948 figures are given for iron ore production, production of concentrates, briquettes and sinter, pig iron, sponge iron, ferrous alloys, and non-ferrous metals. Consumption figures are supplied for charcoal, coke, power, raw materials, and fuel in general. Prices and export values are also presented for the same period, and for the year 1948 detailed figures of the mining and metallurgical industry, including personnel employed, are presented.—B. S. E.

The Circulation of Iron and the Importance of Commercial Scrap as a Raw Material in the Swedish Steel Industry. (Jernkontorets Annaler, 1950, vol. 134, No. 7, pp. 250–300). [In Swedish]. The present and future importance of commercial scrap as a raw material is discussed on the basis of a statistical investigation. Actual and planned extensions of the Swedish steel industry will probably cause a decrease in the demand for imported scrap. Sponge iron is an important raw material for high-grade steel but cannot compete with commercial scrap in ordinary steel production.—B. S. E.

The Russian Iron and Steel Industry. I. P. Bardin. (Przeglad Techniczny, 1950, Jan.–Feb., pp. 5–11). [In Polish]. The author reviews the iron and steel industry of the U.S.S.R., giving data on production. Production of iron increased from 4·2 million tons in 1913 to 5·5 in 1929, and to 14·5 million tons in 1937, and that of steel from 4·2 to 17·7 million tons in the same period. According to official statements in 1946 the aim is to reach annual outputs of iron 50, steel 60, coal 500, and petrol 60 (million tons) in about 15 years.

W. J. W.

The Iron and Steel Industry of the U.S.S.R. in the Fourth Five-Year Plan (1946–1950). M. Szele. (Bányászati és Kohászati Lapok, 1950, vol. 5, June, pp. 335–339; May, pp. 382–384). [In Hungarian]. On the basis of the book with the above title by I. P. Bardin, the development of the iron and steel industry of the U.S.S.R. during the present five-year plan is reviewed. The general tendency appears to be towards decentralization and building of numerous works in extra-European territories. The most important capital investments are: Building and extension of ironworks in the Urals and Siberia, affecting a total of seven works, *e.g.*, Magnitogorsk, Chelyabinsk, and Novotagisk. At two of these works four new batteries of coke ovens, two blast-furnaces, 20 open-hearth furnaces, two Bessemer converters, five electric furnaces, three blooming mills and nine finishing mills are being built, and Magnitogorsk will become one of the largest ironworks in the world. To supply the Leningrad area, steelworks are being built which will utilize iron ore from the Kola peninsula, and coal and peat from the Gulf of Pechora. The mining of ore and the production of refractories are also being stepped up considerably, *e.g.*, 2·78 million tons of firebricks and 980,000 tons of Dinas are to be produced in 1950. Reconstruction of war damage is a heavy burden owing to the very large losses in both materials and skilled personnel. Many ore agglomeration plants are being built: 40% of all the ore produced in the U.S.S.R. is agglomerated, and in some areas the percentage is over 80. Inclusion of 45% agglomerated ore in the blast-furnace burden reduces the coke consumption by 16%, that of lime by 22%, and production is increased by 14%. The average output per ironworks in 1940 was 194,000 tons. In 1950 blast-furnaces with a volume of over 1000 cu. m will produce 50% of the total Russian pig-iron output. The largest blast-furnaces have a volume of 1300 cu. m. and produce 3500 tons of iron per man and year. About 80% of the total steel output is from open-hearth furnaces, mostly standard units of 185–220 tons capacity. Rolling mills, tube mills, research mechanization, and administration are also dealt with.—E. G.

European Recovery Programme and the Future of Steel Production in Italy. E. G. Valentinis. (Costruzioni Metalliche, 1949, vol. 1, Mar.–Apr., pp. 19–21). The future prospects of the Italian iron and steel industry are considered in relation to the recovery plan for Europe. The lack of centralization in Italian production, particularly in steelmaking and rolling, out-of-date equipment, and substantial war damage have handicapped the industry very considerably. The long-term recovery programme for Italy provides for 200-million-dollar investments which should bring production in 1952–53 up to three million tons for ingot steel and one and a half million tons for pig iron. Pre-war, 1947, and 1952–53 figures are given for steel production in Western Europe. Estimated figures are also given for the major Italian projects.—M. D. J. B.

Credits for Iron and Steel Developments and for Research in Brazil. A. Lanarit, jun. (Mineração e Metalurgia, 1950, vol. 15, May–June, pp. 5–7). [In Portuguese]. Some aspects of the problem of capital and technology in Brazil are discussed. Problems urgently needing capital for research in Brazil include: Sintering of ores in view of the enormous quantities of fines in the rich Brazilian ores; exploration of coal deposits; manufacture and exploitation of charcoal (an important possibility in Brazil); steelmaking methods to suit Brazilian conditions (lack of scrap, predominance of pig iron, and development of electric power); and need for flexibility in rolling mills without sacrificing low production costs and high quality.—R. S.

Output of the Brazilian National Iron and Steel Corporation (Volta Redonda) in 1949. (Mineração e Metalurgia, 1950, vol. 15, May–June, pp. 7–9). [In Portuguese]. Volta Redonda produced 226,837 tons of rolled steel products in 1949. Details are given of the tonnages of the various types. The outputs of coal, coke, ore, and limestone in 1949 were 280,683 tons, 271,710 tons, 290,550 tons, and 47,471 tons, respectively. Details of commercial activities and dividends paid are given. The production programme for 1950 is outlined.—R. S.

Iron and Steel Production. (Boletin Minero e Industrial, 1950, vol. 29, June, pp. 313–317). [In Spanish]. This summary of Spanish iron and steel output in 1949 includes the monthly output of iron, steel, rolled products, and raw materials; comparative outputs for the years 1940–49: monthly output of rolled products according to product; percentage distribution of iron and steel ingots and rolled products in home, export, and 'controlled' and 'free' sales.

R. S.

MISCELLANEOUS

Research in Metallurgy, Progress of Industry and Science. W. Oelsen. (Stahl und Eisen, 1950, vol. 70, July 6, pp. 577–582). The importance of fundamental laboratory investigations to the progress of industry is stressed. The history of the application of physical chemistry and thermodynamics to ferrous process metallurgy is discussed and exemplified by the work of Tammann, Schenck, Eichholz, Vögler, Körber, Petersen, Herzog, Wentrup, and Röchling.—J. P.

The Activities of the Verein Deutscher Eisenhüttenleute in 1949. (Stahl und Eisen, 1950, vol. 70, June 8, pp. 485–504). The general organization, the literary, publishing, and educational activities, the work of the 18 constituent committees, and co-operation with other professional and standardizing associations are treated separately in this report by the governing body.—J. P.

The Organization of Iron and Steel Research in France. G. Delbart. (Metal Progress, 1950, vol. 57, Feb., pp. 208–210). The history of the new Institut de Recherches de la Sidérurgie (IRSID) is given by its Director. It is controlled equally by two government departments, and connected with industry by 13 committees. There follows a brief description of the laboratories near Paris, and of the French metallurgical society, Société Française de Métallurgie.—E. T. L.

The Development of Metallurgical Research in Belgium. P. Coheur. (Revue Universelle des Mines, 1950, Series 9, vol. 6, Aug., pp. 203–208). The development over the last 20 years which culminated in the setting up in 1946 of a national centre for metallurgical research is traced. Details are given of the equipment of this centre and of investigations carried out on fundamental metallurgical problems.—B. G. B.

European Research in Physical Metallurgy. B. D. Cullity. (Journal of Metals, 1950, vol. 188, Apr., pp. 648–650). A brief survey is presented of the various fundamental researches in the field of physical metallurgy now in progress in Europe. The countries considered are: England, France, Belgium, Holland, Sweden, Norway, and Germany.—G. F.

The Brazilian Association of Metals. (Mineração e Metalurgia, 1950, vol. 15, May–June, pp. 1–4). [In Portuguese]. The Associação Brasileira de Metais was founded in November, 1943. Particulars are given of its objects, constitution, technical committees, publications, and subsidy from the government.—R. S.

The Spanish Iron and Steel Institute. (Metallurgia y Electricidad, 1950, vol. 14, June, pp. 78–79). [In Spanish]. A

brief description of the organization of the Spanish Iron and Steel Institute is given. The three main departments (apart from administration) are Technical Information, Laboratories, and Industrial Research. The Institute does not possess its own laboratories but has a working arrangement with such official bodies as the Aeronautical Institute. The Research Department has the following Sections: Iron; Steel; Rolling; Casting; Forging; Specialities; and Industrial Applications of Metallurgical Products. Provincial groups also exist. There are 14 working committees for the study of special groups of problems. Other functions of the Institute include the granting of bursaries, etc. It is intended to form later on a Non-Ferrous Metals Department.—R. S.

Pametrada Research Station. (Metallurgia, 1950, vol. 42, June, pp. 22–27.) The Parsons and Marine Engineering Turbine Research and Development Association, (PAMETRADA) is a collective effort by all the British turbine manufacturers to ensure that British turbine design remains in the forefront of its field. Its research station performs engineering, physical, chemical, and metallurgical work on existing and developed turbines and a wide variety of ancillary equipment. Excellent running and testing facilities are available for trials of even the largest marine turbine equipment. The association has developed its own designs of turbines for marine use. Of particular interest is the development work in progress on the Parsons marine gas turbine. Difficulties in the development of this engine include the enormously long creep stress to which the turbine blades will be exposed in marine use, and the lack of information on this aspect of turbine blade materials in current use. The difficulties due to blade damage arising from vanadium compounds in the fuels are also great.—J. J.

Industrial Art: The Statistical Methods of the Control of the Quality. A. Bertschinger. (Microtecnic, 1950, vol. 4, Jan.–Feb., pp. 45–48; Mar.–Apr., pp. 89–96; May–June, pp. 143–147; July–Aug., pp. 225–230). The application of the statistical methods of control to industrial production has brought about price economics and increased production. The approach to methods of application is recommended emphasizing that between designing office and manufacturing process, the duty of the controller is an essential element. The law of distribution is expressed as a simple function from which the area of probability may be obtained. Algebraic methods are used to express the parameters serving to estimate the central tendency and to control it in the sense of the definition given as Shewart's Postulate.—H. D. W.

Experiences in Oxygen Flow Measurement. C. W. Parsons. (Iron and Steel Engineer, 1950, vol. 27, July, pp. 103–109). Some of the problems involved in the metering of oxygen in the different departments of a steelplant are discussed. The following types of meter are examined: Positive displacement meters; the mechanical float type of orifice meter with recorder, with and without integrator; the ring-balance orifice meter; the electric ring-balance orifice meter; and the pneumatic-electric orifice meter. The descriptions of these meters are accompanied by diagrams and photographs. The functions and relative merits of the various types are considered.

M. D. J. B.

Resistance to the Flow of a Fluid through Pipes and Duct Elements. H. W. Hahnemann. (Forschung auf dem Gebeite des Ingenieurwesens, 1949–50, vol. 16, No. 4, pp. 113–119). A review is made of 23 recent papers on this subject. The first four papers give formulæ and diagrams for calculating the pressure drop in straight pipes through which liquids or gases are flowing. The next two papers give, respectively, formulæ for the flow through a pipe of a suspension of a solid (*e.g.*, pulverized coal) in air and a diagram for estimating the flow in a pipe carrying liquid and gas at the same time, while a further paper describes an iterative process for use when there is a change in the type of flow or a change of state in the material during its flow through the pipe (as in tube furnaces). Three papers are concerned with flow of fluids through porous or granular materials. Two papers deal with the design of pipe inlets and outlets and reducing elements joining pipes of different size. There are four papers on losses in bends and junctions. Research on the pressure loss through valves and dampers, described in another paper, has led to new designs having up to 45% less pressure loss. Finally, five papers on metering orifices are reviewed.—H. R. M.

Mechanical Grading. R. Bárta. (Baňský Obzor, 1950, vol. 4, Jan., pp. 1–5; Feb., pp. 27–31; Mar., pp. 36–41). [In Czech]. The mechanical grading and separation of different solid media, solid media from gases, different fluids from each other, fluids from gases, different gases from each other, and solids from fluids are described, the theory is discussed, and brief details of some plants are given.—E. G.

Air-Conditioning Plant for Rooms for Checking Gauges and Instruments. F. Máca. (Strojnický Obzor, 1950, vol. 30, Mar., pp. 33–39). [In Czech]. The design of a room for testing the accuracy of gauges and measuring instruments and air-conditioning systems for such rooms are described.—E. G.

Safety in the Mill. P. B. Ray. (Wire and Wire Products, 1950, vol. 25, Apr., pp. 311, 340–341). The industrial relations manager describes the development of an accident-prevention scheme started by his Company (Titan Metal Manufacturing Co., Bellefonte, Pennyslvania) in 1936. One of the steps taken was the appointment of a five-man safety committee which met weekly to analyse each accident and determine preventive measures.—J. G. W.

Classification of Metallurgical Literature and Its Mechanization. L. Jeníček. (Hutnické Listy, 1950, vol. 5, May, pp. 205–209). [In Czech]. The author reviews methods of classifying technical literature with special reference to ferrous and non-ferrous metallurgy and discusses the advantages and disadvantages of the systems. The application of punched card systems is described and the suitability of the subject classifications for such a card indexing system is discussed. The author criticizes the practical value of the decimal classification system for technical libraries.—E. G.

The Periodic System and Electronic Configuration. L. H. Acera. (Metalurgia y Electricidad, 1950, vol. 14, Mar., pp. 43–47). [In Spanish]. The author discusses the relation of the position of each element in the periodic system to the four quantum numbers of the electron : principal ; secondary ; magnetic ; and spin. A table is given, showing the electronic configuration of all elements according to the latest data. The lack of sufficient study of some of these data is stressed.

Radioactive Isotopes in Chemical and Industrial Research. H. D. Taylor. (British Coal Utilisation Research Association, 1950, vol. 14, Aug., pp. 293–303). This review briefly outlines the principles and methods of radiochemistry and indicates a number of applications which have already been made. There are 106 references.—R. A. R.

Radioactive Tracers in Metallurgical Research. W. S. Eastwood, W. G. Marley, H. M. Finniston, and A. E. Williams. (Ministry of Supply : H.M. Stationery Office, 1950). The booklet is in four chapters. Chapter 1 describes in some detail the nature and methods of production of isotopes and the nuclear processes by which they decay to a lower energy state. Chapter 2 describes the methods for detection and counting of the nuclear changes. Chapter 3 discusses some experimental work on metallurgical problems which have been tackled with radioactive tracers, and suggests possible fields in metallurgy in which tracers might find research application. Chapter 4 deals with the hazards and precautions to be observed in the use of tracers. The first appendix defines units of radioactivity and radiobiological dose. The second appendix gives brief specifications for radiation monitors. The third appendix consists of a table for finding the shield thickness for laboratory sources of radiation.

R. A. R.

Research from the Standpoint of the Smaller Business Enterprise. G. H. Clamer. (Journal of the Franklin Institute, 1950, vol. 249, May, pp. 367–391). This paper is from a symposium on "Research for Management" sponsored jointly by the American Society for Testing Materials and the Franklin Institute. The author cites six case histories of the successful application of metallurgical research with which he has been connected. These were : (1) The development of bearing alloys with higher lead and lower tin contents ; (2) the production of non-ferrous alloys to rigid chemical specifications from brass and bronze scrap ; (3) the Ajax-Wyatt submerged resistor furnace ; (4) the Ajax-Northrup high-frequency furnace ; (5) the Ajax-Tama-Wyatt induction furnace for aluminium ; and (6) the submerged resistance Ajax-Hultgren furnace.—R. A. R.

Job Analysis and Evaluation in Personnel Management. K. A. Dunn. (Iron and Steel Engineer, 1950, vol. 27, Jan. pp. 81–87). The subject of fixing rates for different clerical jobs is discussed. Various methods of job valuation are described and the relative merits studied. The author

describes a method used with success at the Ford Motor Company based on 15 factors such as previous experience required, complexity, ability to work without supervision, etc. Job valuation is discussed by employee and management and the experience of outside consultants is sought. In many cases job analysis is said to have revealed inadequacies which could not have been discovered by any other method. With existing personnel the tendency is for job analysis to recommend an improvement in the salary scale; when, however, posts become vacant through retirement a re-assessment on the true value of a job can be examined on a scientific basis. Job analysis can also be used to fix a scheme of salary grades. M. D. J. B.

Apprentice Training. G. M. Kennedy and T. W. Boulter. (Iron and Steel Engineer, 1950, vol. 27, Feb., pp. 81–91). The first part of this article describes a scheme introduced by the Carnegie-Illinois Steel Corp. for the training of apprentices, based on four objectives: The development of skill in the duties of the trade; the advancement of technical knowledge; the understanding of industrial management; and the encouragement of self-education and of ambition for advancement. In the second part a description is given of the apprenticeship training at John A. Roebling's Sons Co., where intelligence, mechanical comprehension, and personal inventory tests are used to determine qualifications. Details of instruction given to machinist, electrician, tinsmith, carpenter, bricklayer, welder, patternmaker, and blacksmith apprentices are described. The subjects taught and the hours spent on various jobs and machines are given.—M. D. J. B.

Costing and Modern Accounting Methods in the Metal Industries. IV—Recording and Control of Capital Expenditure. V—Computing and Recording Depreciation. VI—Providing for Interest on Capital; Building up Sinking Fund for Plant Replacement. VII—Ascertaining the Balance of Taxable Profit. S. H. Withey. (Metallurgia, 1950, vol. 41, Mar., pp. 255–258; Apr., pp. 308–310; May, pp. 397–399; vol. 42, June, pp. 20–21). Conclusion of a series of articles, (*see* Journ. I. and S.I., 1950, vol. 166, Oct., p. 166).—R. A. R.

Information Departments for the Utilization of Steel. U. Galluzzi. (Costruzioni Metalliche, 1949, vol. 1, July–Aug., p. 26). [In Italian]. The author discusses the various organizations in different countries which bring to the user information concerning the utilization of steels and the economics involved.—M. D. J. B.

BOOK NOTICES

EINECKE, G. "*Die Eisenerzvorräte der Welt und der Anteil der Verbraucher- und Lieferländer an deren Verwertung.*" 2 vols. 8vo. Text, pp. ix + 418; Atlas, pp. vi + 100. Düsseldorf, 1950: Verlag Stahleisen m.b.H. (Price DM 66.–)

This is a useful guide to the iron ore resources of the world, their location, extent, nature, and utilization. The treatment is detailed and comprehensive in the Teutonic manner. The first volume contains 370 pages of text (including 190 statistical tables), a bibliography comprising 242 items, and an index with about 6500 references; the second volume contains 100 maps. Altogether over 3000 iron ore deposits are mentioned in one or both volumes. Geological, metallurgical, economic, and statistical considerations are given due weight in the description and analysis of the material, which is arranged according to the 'spheres of interest' of the main consuming areas. This arrangement is not always satisfactory, some of Britain's principal suppliers of ore (*e.g.*, Sweden, North Africa, Spain, France) being excluded from the British 'sphere.'

Dr. Einecke's estimates of iron ore reserves add up to a world total (in thousand million metric tons) of 95 'certain' and 'probable' reserves (containing 41 iron) and 435 'possible' reserves (including proved but uneconomic deposits), of which the U.S. sphere (American continent, excluding Newfoundland) accounts for 28·5 certain and probable (12·1 iron) and 116 possible, the British Commonwealth (excluding Canada and Central Africa, including Newfoundland) 25·6 certain and probable (12·3 iron) and 37 possible, and the Soviet Union 12·7 certain and probable (5·2 iron) and 257 possible. The Soviet figures (and therefore the world totals) include 3·9 certain and probable and 253 possible reserves of ferruginous quartzites; they exclude the Manchurian reserves (3 certain and probable).

It is inevitable that a 'stock census' of this kind quickly becomes out of date. Of the deposits which have achieved prominence in recent years, the Quebec–Labrador field is fully dealt with, Venezuela in fair detail, but very little is said about Southern Rhodesia. Nor is it surprising that the very large amount of statistical information provided is not all equally reliable. It is suggested (Table 172), for example, that the average iron content of ores consumed in the U.K. is 35 instead of 40%. The discussion of the United Kingdom Steel Development Plan is also out of date. Much useful information is, however, given on the ore consumption and exports of the main ore producers, and in most cases production statistics of iron ore, pig iron, and crude steel are provided.

The atlas volume contains 100 maps showing the location of iron ore deposits, but not their extent or analysis, which are described at length in the text. Manganese ore and coal deposits are also shown. The distribution of maps is rather uneven. The United Kingdom and North West Africa are only given one each, compared with eight for Sweden, six for France, five for Spain, three each for Czechoslovakia and Poland, and 16 for Germany.

Though falling short of perfection in several respects, Einecke's "*Eisenerzvorräte*" will remain for many years one of the foremost works of reference on the subject, to be consulted in conjunction with more up-to-date, more forward-looking, or more specialized publications, such as the recent United Nation's Organization survey of "World Iron Ore Resources and their Utilization" (August, 1950), which has special reference to the use of iron ores in underdeveloped areas.—P. WYKEMAN

"*Fortschritte auf dem Gebiete der Phosphatierung.*" 3 Band. Zusammengestellt und herausgegeben von W. Kohler. 8vo, pp. 141. Illustrated. Weinheim/Bergstrasse 1950: Verlag Chemie G.m.b.H. (Price DM 7.80)

This third volume of a series devoted to advances in the phosphatizing field is a collection of 14 papers, five by W. Machu. The paper by Machu on the topochemistry and kinetics of corrosion processes generally, and that by A. Wüstefeld on phosphatizing, are useful summaries of the views of these workers. G. Schikorr presents results on the atmospheric corrosion resistance of steel phosphatized by the cold process. Of the remaining papers, that of Machu on electro-phosphatized coatings seems the most notable to the reviewer, but it is likely that anyone concerned with the principles or practice of phosphatizing will find something in the present volume of particular interest.

The format of the book is somewhat cramped; the printing, however, is adequate.—T. P. HOAR

GEISSEREI SONDERAUSGABE. "*Konstrukteur und Giesser.*" 4to, pp. 88. Düsseldorf, 1951.

This special issue of *Giesserei* contains the following papers: Correct Design for Moulding and Pouring and Its Effect on the Cost of Castings (J. H. Küster); The Properties and Design Characteristics of Grey Cast Iron (E. Hugo and C. W. Pfannenschmidt); High Quality Cast Steel (A. Heuvers); Cast Structural Parts (W. Trommer); The Correct Design of Steel Castings (G. Schraidt); Some Rules of Construction for Steel Castings (H. Resow); A Report on the Constructional Characteristics of Malleable Iron (F. Roll); Principles for the Use of Aluminium Castings (A. Buckeley); The Design of Parts for Sand- and Die-Casting in Light Metals (P. Schneider); Planning the Die-Casting of Copper-Base Alloys (C. A. Piel); Design and Construction of Patterns (J. Hagen); and Welding or Casting? (E. Piwowarsky). A bibliography of 38 references covering the period 1925–41 is also appended. Abstracts of the papers of metallurgical interest will appear in the Abstract Section of the *Journal*.—J. P. S.

GRASSIE, J. C. "*Elementary Theory of Structures.*" 8vo, pp. viii + 392. Illustrated. London, 1950: Longmans, Green and Co. (Price 25*s.*).

This book deals in a most comprehensive manner with the elementary theory of structures. It is written strictly within the confines of statically determined structures; the approach to the subject is pleasingly scholarly, yet sufficiently practical to be widely read by both designer and student. The 19 chapters cover geometrical properties

of sections, the representation and resolution of forces, the solution of simple and more complex trusses, the comprehensive analysis of simply supported beams, live loads and the theory and application of influence lines, elastic deformation of structures, and the simple study of columns and three-dimensional structures.

A feature of the book is the extensive use which the author has made of graphical solutions. In structural engineering, where it is essential to get a true picture of the play of forces and flow of stresses, the power of graphical methods cannot be overestimated. The reader will find the chapters on Williot diagrams particularly useful and a sound basis for the study of elastic deformations and pre-stressing in structures.

A considerable portion of the book is devoted to the study of influence lines. This is a most welcome departure from the standard practice of many textbooks published in Great Britain which often do little more than mention this elegant method of solution. Here the theory and application of influence lines is treated in full and extended beyond the study of rolling loads and simple beams to direct forces, bending moments, and shear forces in individual members of complex triangulated structures. The study of columns is dealt with in a straightforward and simple manner and, although the integration of the fundamental elasticity equation, leading to Euler's formulæ for critical loads, is not given, this does not affect the clarity of the exposition. The chapter on elementary statically determined space structures completes this excellent text-book.

A large number of worked-out examples are given and each chapter is followed by exercises with answers. The book will appeal to civil engineering students and to designing staff in consulting and constructional engineering offices. It is well edited and pleasantly presented, the subject matter is clearly and concisely dealt with, and the large number of line diagrams are well drawn.

M. D. J. BRISBY

GUMZ, W. "*Gas Producers and Blast Furnaces—Theory and Methods of Calculation.*" 8vo, pp. xiii + 316. New York, 1950 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price $7)

The main emphasis of this book is explained by its sub-title : 'Theory and Methods of Calculation.' No attempt is made to give detailed accounts of gas producer and blast-furnace practice, and, in general, those aspects of the theory of the processes are selected which are required for the methods of calculation used. The basic concept of these methods is the attainment of equilibrium at a certain zone of the shaft.

The first part of the book—'Gas Producers'—in fact includes introductory matter required also for the treatment of blast-furnaces. Thermochemical equations are explained, an elementary derivation of equilibrium constants and ways of handling them are outlined, and a brief account is given of the gasification mechanism. This introduction leads up to the development of a series of simultaneous equations involving material and heat balances, and much space is devoted to the various methods available for their solution for both equilibrium and non-equilibrium conditions. The treatment is applied to the performance of various types of gas producer and the calculation of the influence of operating conditions, such as blast moisture, blast preheat, oxygen enrichment, pressure, and the use of oxygen–steam mixtures. Results calculated for many cases show excellent agreement with experimental data, providing support, in the field of gas producers, for the validity of the basic concept of the methods of calculation given.

In the second part of the book the methods applied to gas producers are extended to deal with the more complicated conditions of the blast-furnace. To introduce the reader to this process, equilibria in the reduction of iron ores and the reactions and heat changes in the hearth and in the different zones of the shaft of the furnace are outlined. The ideas of ore reducibility and coke reactivity are dismissed as useless. The methods of calculation are applied to a Swedish charcoal blast-furnace, to the cases of high top pressure and oxygenated blast, and to a reduction process involving high pressure together with oxygen and water-gas. Finally, calculations are made on the effects of operating conditions on the performance of cupola furnaces. Though the calculated and experimental results of all the cases considered agree well, the scope of the examples cannot be admitted as sufficient to establish the applicability of the methods of calculation to blast-furnaces in general ; this, in fact, being rendered doubtful by, for example, the treatment given of conditions in the 'preheating' zone of the stack, in which no carbon deposition is allowed for. However, any new quantitative contribution to the theory of blast-furnaces must be welcomed, and it is now up to students of the process to test these potentially invaluable methods over a wider range of conditions.

The last—and shortest—part of the book deals with reaction kinetics, it being concluded that in full-scale processes chemical reactions are not rate-controlling. Great emphasis is given to the inadvisability of applying laboratory and pilot-plant experimental results to full-scale processes, the uselessness of the numerous determinations which have been made of coke reactivity being given as an example.

The Appendix contains a set of tables, useful in the calculations, giving the properties of gases and of steam–air or gas mixtures ; the enthalpies of pig iron, slag, carbon, and gases ; heats of formation ; values of equilibrium constants ; and metric to English unit conversion tables.

Of the book as a whole it must be said that the author's arguments would be less laborious to follow if more care had been taken to avoid—or at any rate to correct—mistakes. These crop up, for example, even in one of the fundamental equations (equation 13) and in equation 438 in the discussion of the theory of the blast-furnace process.

S. KLEMANTASKI

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS. "*The Fifth General Assembly of the International Council of Scientific Unions, held at Copenhagen, Sept.* 14–16, 1949. *Reports of Proceedings.*" Edited by F. J. M. Stratton. 8vo, pp. 249. Cambridge, 1950. Cambridge University Press. (Price 7*s.* 6*d.*)

These reports are mostly concerned with the internal organization of the "Adhering Bodies," the organization of the International Union itself, and its relations with the United Nations Educational, Scientific and Cultural Organization. The adhering bodies are, at present, the International Astronomical Union, the International Union of Geodesy and Geophysics, the International Union of Pure and Applied Chemistry, the International Radio-Scientific Union, the International Union of Pure and Applied Physics, the International Geographical Union, the International Union of Biological Sciences, the International Union of Crystallography, the International Union of Theoretical and Applied Mathematics, and the International Union for the Study of the History of Science. The work being carried out by the International Union of Pure and Applied Chemistry includes the preparation on index cards of tables of constants, the issue of mimeographed reports on reagents for mineralogical analysis, and the revision of the rules for the nomenclature of inorganic compounds and complexes. It is also interesting to note that it is with the help of this body, and the financial support of U.N.E.S.C.O. that the issue of the Gmelin series of treatises on inorganic chemistry and the Beilstein series on organic chemistry have been able to continue their appearance. The International Union of Pure and Applied Physics reports, *inter alia*, the holding of colloquia on statistical mechanics, on nuclear physics, and on very low temperatures. The Union has also been able to provide scholarships oversea for five students per year. The International Union of Crystallography reports the continued appearance of *Acta Crystallographica*, and the preparation of *International Tables for the Determination of Crystal Structure* was well in hand at the time of publication of these Reports. Generous financial help from U.N.E.S.C.O. and from British and American industrial firms and other organizations is gratefully acknowledged. The International Union for the Study of the History of Sciences continues to publish *Archives Internationales d'Histoire des Sciences* ; one of its Commissions is producing a report, on an international basis, on "Teaching of the History of Science," and another has given financial help to the publication of Lavoisier's correspondence by the Académie

des Sciences de Paris. In all, these Reports, though containing little of direct interest to metallurgists, provides a useful picture of international co-operation in fields of science other than their own.—J. P. S.

MACHU, W. "*Die Phosphatierung: Wissenschaftliche Grunlagen und Technik.*" 8vo, pp. xii + 306. Illustrated. Weinheim/Bergstrasse, 1950: Verlag Chemie G.m.b.H. (Price DM 26.–)

This monograph on the principles and practice of the phosphate treatments available for metal surfaces, especially ferrous, deserves to become widely known. Dr. Machu has critically condensed into some 300 pages a scattered body of knowledge, and has succeeded in compiling not only a reference book—there are over 900 citations—but a readable text. The early chapters on the properties of metallic phosphates, the chemistry of the phosphatizing process, and on the properties of phosphate coatings on steel are full yet concise. Phosphatizing of non-ferrous metals is less well understood, and the treatment is here less critical, but there are good accounts of the development of low-temperature phosphatizing processes and of cathodic phosphatizing. The chapters devoted to descriptions of technique naturally lay emphasis on German rather than Anglo-American 'know-how,' and for this very reason they may prove of especial interest to British and American readers. The concluding chapters on phosphatizing defects, control of baths, and testing of coatings are adequate.

The book is excellently produced, although the bold type and semi-glossy paper will be tiring to the eyes of some readers.—T. P. HOAR

RAIT, J. R. "*Basic Refractories: Their Chemistry and Their Performance.*" With a preface by Dr. A. T. Green. 8vo, pp. 410, 109 figs. and 112 tables. London, 1950: Iliffe and Sons, Ltd. (Price 60*s.*)

In this volume much of the fundamental chemistry of importance in the manufacture and behaviour of basic refractories has been collected and presented in a manner of particular interest to the research worker in this field. However, the wealth of data it contains will be of even wider use for reference purposes.

The available raw materials used in the manufacture of basic refractories are surveyed and analyses are given of calcined magnesites, dolomites, magnesium silicate minerals, and chrome ores from many parts of the world. After a brief description of the processing of basic refractories, the main components to be found are outlined. Since the five-component system $CaO–MgO–SiO_2–Al_2O_3–Fe_2O_3$ is able to provide sufficient information for the adequate computation of the constituents of most basic refractories including chrome–magnesite, the six-component system containing Cr_2O_3 is not considered.

A comprehensive survey of the mineralogical and chemical properties of the five components is made, and all the available information on the various relevant binary, ternary, quaternary, and five-component systems is collected. There follows a description of an extensive experimental investigation made by the author from 1938 onwards, for which he was awarded the degree of Doctor of Science. In this work, additional thermal equilibrium data were obtained so that the elucidation of the constitution of basic refractories was brought nearer completion. The X-ray diffraction method used in this investigation is described in considerable detail, and many powder X-ray diffraction photographs and photometer curves are given. The latter would have been easier to read if drawn on vertically ruled paper. Additional evidence of the character of the crystalline phases in the various mixes was made by petrological examination of thin sections, and some excellent photographs of these are reproduced. After various ternary systems had been studied, a calculation of the lattice spacings of spinel solid solutions was made. Fusion temperatures were measured, and the phase regions in the systems $CaO–MgO–SiO_2–Fe_2O_3$, $CaO–MgO–SiO_2–Al_2O_3$, $CaO–MgO–Al_2O_3–Fe_2O_3$, and $MgO–SiO_2–Al_2O_3–Fe_2O_3$ were determined. Detailed examples are given of the method of calculation of the constitutions of the various mixes. The five-component system is also treated in the same way, and a number of ternary and quaternary systems within the five-component system are studied.

Constitutions of dolomite, magnesite, and forsterite refractories are worked out from X-ray diffraction and petrological examination combined with a knowledge of the composition and of the phases likely to be present. Further thin-section photographs and photometer curves are reproduced. Chrome–magnesite refractories are treated separately and this section includes data on the constitution of chrome ores and their reaction products after firing. Examples are given of the calculation of average molecular constitution and lattice spacing of spinels in the raw ores and after firing.

The significance of the formation of liquid in basic refractories is explained. Tables of the temperatures of formation of liquid in mixes appropriate to stabilized and semi-stabilized dolomite bricks, as well as in magnesite refractories, are given. Valuable conclusions are drawn with regard to the desirable constitutions of these refractories. The undesirable influence of montecellite upon liquid formation in chrome–magnesite bricks is demonstrated, and further useful conclusions concerning the high-temperature properties of these bricks are reached.

The importance of this fundamental work is emphasized by the manner in which it can be used to explain the mechanism of destruction of basic refractories under service conditions. A typical example is described in which the author is able to suggest the mechanism of flaking of chrome–magnesite bricks in the open-hearth furnace. Also the factors which influence the behaviour of chrome–magnesite, magnesite, and semi-stabilized dolomite in the walls of a basic electric furnace are outlined, and some conclusions are reached regarding the wear of dolomite hearths. A critical comparison of different makes of magnesite blocks used in a mixer lining is made. The wear on ladle linings used for ferrochromium and the failure of some magnesite bricks in open-hearth tap holes are explained.

This book has a comprehensive bibliography containing 219 references and an appendix of X-ray diffraction data on many of the compounds of interest in basic refractories. On account of the value of this work as a reference book its layout is particularly important, and therefore in a future edition the arrangement of tables and figures with respect to the text should be improved.—T. E. DANCY

NEW PUBLICATIONS

BRITISH STANDARDS INSTITUTION. B.S. 1121: 1951. "*Methods for the Analysis of Iron and Steel.*" Part 17: "*Titanium in Permanent Magnet Alloys.*" Pp. 10. (Price 2*s.*); Part 18: "*Chromium in Ferro-Chromium.*" Pp. 6. (Price 1*s.*). London: The Institution.

BOUMAN, J. "*Selected Topics in X-Ray Crystallography from the Delft X-Ray Institutes.*" (Monographs on Theoretical and Applied Physics, III) la. 8vo, pp. xv + 375. Illustrated. Amsterdam, 1951: North-Holland Publishing Co. (Price £3 16*s.*)

COLEMAN, H. S. "*Laboratory Design.*" Pp. ix + 393. New York: Reinhold Publishing Corp. (Price $12)

FISCHER, GEORGE, LTD. "*An Outline of the Development of the George Fischer Works.*" Fcp., pp. 23. Illustrated. Schaffhausen, 1950: George Fischer, Ltd.

JOHN, A. H. "*The Industrial Development of South Wales 1750–1850.*" 8vo, pp. x + 201. Cardiff, 1950: University of Wales Press. (Price 12*s.* 6*d.*)

KIEFFER, R., and W. HOTOP. "*Fer et Aciers Frittés.*" En collaboration avec H. J. Bartels et F. Benesovsky. Traduit de l'allemand par R. Chouteau et R. Meyer. 8vo, pp. xx + 573. Illustrated. Paris, 1951: Dunod.

MEDICAL RESEARCH COUNCIL. Memorandum No. 25. "*The Social Consequences of Pneumoconiosis among Coalminers in South Wales.*" By P. Hugh-Jones and C. M. Fletcher. 8vo, pp. viii + 54. London, 1951: H.M. Stationery Office. (Price 1*s.* 9*d.*)

WESTWOOD, W., and A. MAYER. "*Chemical Analysis of Cast Iron and Foundry Materials.*" 8vo, pp. 565. London, 1951: George Allen and Unwin Ltd. (Price 42*s.*)

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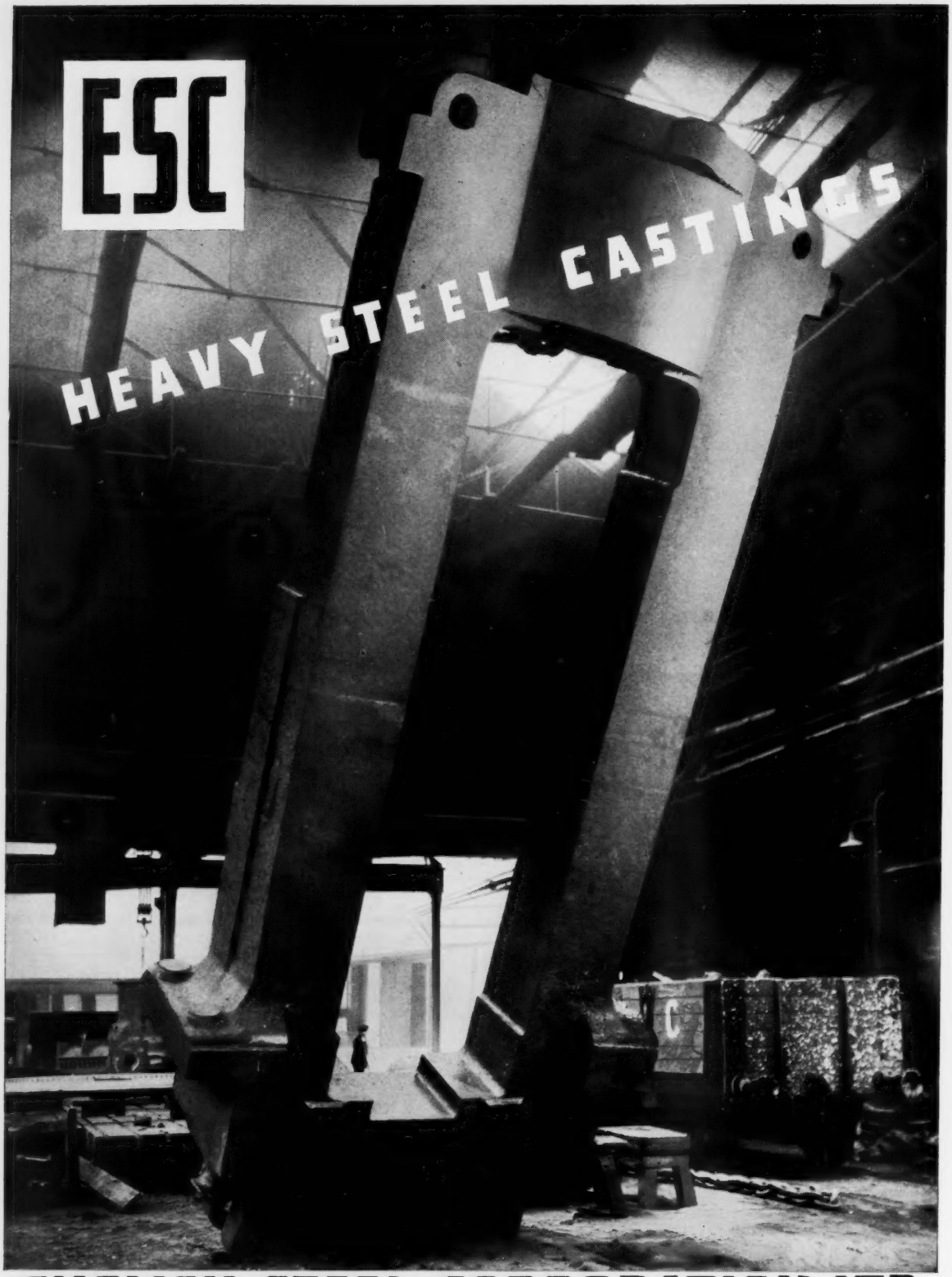

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RICHARD MATHER, B.Met.(Hons.), F.I.M.

RICHARD MATHER, Chairman and Managing Director of the Skinningrove Iron Company, was born in 1886. He was educated at the Royal Grammar School, Sheffield, and later at the University of Sheffield, where he obtained an honours degree in metallurgy in 1907. After graduation, he took his first appointment as a metallurgist with the firm of Cochrane and Company, Ironfounders, of Middlesbrough. Four years later he joined the staff of the Research Department, Woolwich, also as a metallurgist, and remained there until 1919. From that time until 1925, Mr. Mather was Metallurgical Inspector to the Government of India, and during two periods, from 1923 to 1924 and from 1926 to 1927, he was Technical Adviser to the Indian Tariff Board.

Mr. Mather re-entered the productive side of the industry in 1927, when he became Deputy General Manager of the Tata Iron and Steel Company at Jamshedpur, India. He was appointed Technical Director of that Company in 1930, and during the following ten years he was mainly responsible for plant developments which more than doubled the output of the Jamshedpur works. He returned to England in 1940, and in 1941 became Consultant to Messrs. Pease and Partners, Limited. He was appointed a Director of the Company in 1942, and in the same year he was elected Chairman and Managing Director of the Skinningrove Iron Company. The programme of development now nearing completion at Skinningrove will increase the efficiency of operation and raise plant capacity by over one-third.

From 1946 to 1949, Mr. Mather was a member of the Iron and Steel Board of the Ministry of Supply. He was the representative of British employers at meetings of the Iron and Steel Committee of the International Labour Organisation in the U.S.A. (1946), in Sweden (1947), and at Geneva (1949); he was elected Chairman of the Employers' Group at the 1947 and 1949 meetings.

Mr. Mather became a Member of Council and of the Executive Committee of the British Iron and Steel Federation on their reconstitution towards the end of the war; he is also Chairman of two committees and a member of some others. When the British Iron and Steel Research Association was formed in 1945 he became a Member of Council, and in 1950 he was elected Chairman. He was Chairman of the North-East Coast Steelmakers' Association in 1948. Mr. Mather joined The Iron and Steel Institute in 1913, and was elected a Vice-President in 1945. At the Autumn General Meeting of the Institute in 1950 he was nominated by the Council to become President for the year 1951-52, and he took office at the Annual General Meeting held last month. He is a Founder Fellow of the Institution of Metallurgists.

Richard Mather, B.Met.(Hons.), F.I.M.

President 1951-1952